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Western Corn Rootworm Sex Pheromone; Field Trapping Studies

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WESTERN CORN ROOTWORM SEX PHEROMONE;

FIELD TRAPPING STUDIES

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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INTRODUCTION

Entomologists have placed emphasis on the development of ecologically acceptable means of manipulating and monitoring economic insect pest species. Sex pheromones for survey and detection of insect pests, have been investigated. Research has indicated the potential of pheromones in detection work with the western corn rootworm (WCR), Diabrotica virgifera, (Leconte) and with the northern corn rootworm (NCR), Diabrotica longicornis, (Say). The term corn rootworm (CRW) will be used for the designation of both northern and western species. The potential use of sex pheromones to assess field populations is for determining economic thresholds. Pheromone research may allow possible use of insecticides in a more judicious manner, related to timing of application. Pheromone and insect behavior studies have encouraged better approaches to insect survey and control There have been extensive research efforts in the sex pheromone field, yet considerable work on the potential of pheromones in pest management programs remains for most economic pests.

The interest created with pheromones has been associated with a desire to reduce prophylactic chemical treatments for insect control. The agro ecosystem has been heavily dependent on chemicals to which many economic pests are developing resistance. Therefore, new insect pest control techniques, such as pheromone-based programs may have promising potential to avoid excessive use of insecticides which can disrupt the environmental quality and stability of the agro ecosystem (Beroza, 1970).

Current control measures for the corn rootworm consist of crop rotation and soil insecticides. The soil insecticides are incorporated in a 7" band or broadcast in granular form over the rows at planting. To a lesser extent adult corn rootworm beetles have been sprayed in the field when the female beetle emergence was essentially complete and before many eggs were laid in the soil. Proper timing of the insecticide should curtail egg deposition and prevent larval damage to corn the following year.

A potential use for corn rootworm sex pheromones would be to monitor field populations, once the chemical structure has been identified and synthesized (Bartelt and Chiang, 1977). However, the large quantities of pheromone necessary may present limitations to such pheromone-based monitoring programs. Many biological factors must be evaluated which may affect pheromone attractiveness under varying climatic conditions. These include the purity of the pheromone, trap design, trap height, trap placement, pheromone age, pheromone concentration, beetle density, and population age structure. An understanding of population dynamics and insect behavior is necessary. There is insufficient information regarding the seasonal and daily activity, flight behavior and dispersal of the CRW beetle (Witkowski et al., 1975). Elucidation of the biological role of the sex pheromone on the reproductive pattern of the insects is needed to obtain greater reliability and efficiency in monitoring field populations.

Fields with economic populations could be readily located utilizing efficient detection techniques based on pheromone-baited sticky trap catches. The economic damage level for the CRW beetle was determined to be one beetle per plant (Kuhlman and Wedberg, 1976).

Research accomplished to date with insect sex pheromones used in insect survey or control programs include the following insect species: codling moth, Laspeyresia pomonella (L); cabbage looper, Trichoplusia ni (Huber); lesser peach tree borer, Synathedon pictipes (Grote and Robimson); gypsy moth, Porthetria dispar (L); and the pink bollworm, Pectinophora gossypiella, (Saunders).

The purpose of this study was to explore the potential of monitoring field populations of the NCR and WCR beetles with pheromone-baited sticky traps. Predictions of CRW infestations in corn fields on a single field basis have yet to be achieved.

The objectives of this study were:

1. To determine the effects of trapping procedures on CRW beetle trap catch variability: trap design, trap height, pheromone age, pheromone concentration and beetle density.
2. To determine the impact of environmental factors on daily trap catch variability: temperature (°C), wind speed (m/sec), and relative humidity (%) taken at hourly intervals.
3. Correlate CRW beetle-per-plant counts with daily trap catch on a field-to-field basis for control recommendations.

II. LITERATURE REVIEW

The sex pheromone of the western corn rootworm (WCR) was shown to exist by Ball and Chaudhury (1973). Guss (1976) and Bartelt and Chiang (1977) have also extracted the WCR pheromone from virgin females. These workers have observed that the WCR sex pheromone was attractive to male beetles of both the WCR and NCR.

The sex pheromones are included in a broad field of similar chemical substances which influence insect behavior and communication (Brown et al., 1970). Four major categories of chemical messengers including sex pheromones were defined by Brown et al. (1970) as pheromones, allomones, kairomones and hormones.

Pheromones or telergones (Kirschenblatt, 1962) are defined as: tele-afar, and ergon-action. The pheromone term can be broken down into the words "pherin," to carry, and "Hormon," to excite or stimulate (Beroza, 1970). Brown et al. (1970) states that pheromones are chemical substances produced by an organism that serve in intraspecific communication by influencing behavioral responses adaptive to that species.

Generally the female sex pheromone serves to excite or stimulate the male before copulation with most insect species. The male may also release a sex pheromone for the purpose of sexually arousing or exciting the female, making the female more receptive to the male insect's advanced with some insect species. This has been shown to exist with the male lesser wax moth, <u>Achroea grisella</u>, by Jacobson (1965). Pain (1973) used other terms to designate pheromones:

ectohormones, parahormones, exohormones and telergones. Pheromones may include alarm and defense pheromones, trail marking pheromones, clustering pheromones and mutual recognition pheromones.

Allomones are chemical substances emitted by an organism which involve interspecific communication. These substances act as repellents towards other aggressors. The behavioral reaction is adaptively favorable to the emitter. Allomones include toxins, antibiotics and venoms which protect the emitter (Brown et al., 1970).

Kairomones are chemical substances that are involved in interspecific communication with the adaptive benefit favoring the recipient, rather than the emitter. Kairomones include phagostimulants that mediate positive responses between the predator and prey, herbivores and their plants, and parasites with their hosts (Brown et al., 1970).

Hormones are chemical substances which are active within an organism and cannot be thought of as mutually exclusive from the other three categories of chemical messengers (Brown et al., 1970).

Wright (1963) indicated that molecular vibrations are involved with insect sex attractant perception. The low frequency molecular vibrations provide the physical basis of the odor. The insects olfactory apparatus located at the base of the antennae, is tuned to a narrow frequency band. It generates a nerve impulse when approached by odorous molecules with the appropriate configuration and vibration matching the receptors frequency to initiate a behavioral response.

Kellogg et al. (1962) and Wright (1958) described the behavioral response of a hypothetical insect to a pheromone source. The insect must first perceive a threshold concentration of the pheromone to initiate flight. The insect responds to the pheromone by flying upwind in the general direction of the pheromone source. This is an aemeotaxis type reaction,an orientation to an air current (Farkas and Shorey, 1972). Kellogg et al. (1962) stated that an insect would continue to fly upwind as long as it remains within the active space of the aerial trail. The active space is defined as a zone around or downwind from the pheromone that contains a density of molecules at or above the behavioral threshold concentration. The upwind flight would cease if the insect moves out of the active space. Crosswind or downflight movements are made until the trail is regained. The insect would end its search by arresting flight and landing near the pheromone source.

Farkas and Shorey (1972) reported that the pink bollworm moth does not utilize this mechanism of anemotaxis in steering to a sex pheromone source. Chemical trails were observed to be followed in a flight tunnel when the air movement was eliminated. Other mechanisms were thought to have been used by the male moth to determine the direction of the pheromone source. Wright (1958) proposed a mechanism by which a flying insect could steer to a distant pheromone source without using anemotaxis. The hypothesis was based upon observations of the physical nature of the pheromone trail. Wright stated that the spaces between the odorous filaments of the trail are positively correlated with the distances from both the longitudinal axis of the odor active space. An insect would perceive a series of discontinous chemical signals in the form of pulses as it flies through the sequence of filaments in the direction of the source. The insect would sense a decrease in the time between pulses and would be inhibited from turning as it approached the source.

Farkas et al. (1974) and Farkas and Shorey (1972) demonstrated that the pink bollworm moth responded to a pheromone source in a zig-zag manner. Farkas et al. (1974) added that the forward progress and air speed of the insect along a zig-zag course decreased as the pheromone concentration increased. The lateral amplitude of the zig-zag would approximate the lateral dimension of the pheromone trail (Farkas and Shorey, 1972).

Insects which follow chemical terrestrial trails appear to exhibit a behavior similar to an insect flying toward a chemical source (Shorey and Farkas, 1973). Ants characteristically follow a terrestrial trail in a zig-zag pattern similar to flying insects movement toward a pheromone source (Wilson, 1962). Chemotropotaxis may be a mechanism used by ants following a terrestrial pheromone trail (Hangartner, 1969). An ant following a terrestrial pheromone trail may sense a lower pheromone concentration to one side with the antenna. The ant may respond by turning the opposite way exhibiting a zig-zag turning pattern.

Wingless males of the cabbage looper have been observed to follow a terrestrial pheromone trail (Shorey and Farkas, 1973). The male moth normally flies toward a sex pheromone source by following an aerial trail. Both terrestrial and aerial chemical trail followers may be regulated by similar mechanisms which detect pheromone concentrations in a comparable manner.

The arrestment of flight by a flying insect, following an aerial pheromone trail, is regulated by the number of stimuli, including chemical concentration and visual cues (Farkas et al., 1974). Male cabbage looper moths have been observed to visually orient and hover adjacent to a model of a female, even though the model was located 2 cm to one side of a pheromone source (Shorey and Gaston, 1970). The female gypsy moth (emitting no pheromone) was placed 15 cm upwind from a hidden sex pheromone source (Doane, 1968). The males were unable to locate her, even though they did overshoot the source and pass a few cm from the female. A similar female located 15 cm downwind from the source was readily located by the males and attempted copulation occurred.

The effective distances for chemical communication were influenced by: (1) pheromone emmission rate of sender; (2) behavioral threshold for response to pheromone by receiver; (3) wind velocity; (4) length of time sender releases pheromone; and (5) flight speed of receiver, as described by Bossert and Wilson (1963) for an insect. The theoretical maximum distance of pheromonal chemical communication were based on the first three factors.

Sower et al. (1973) calculated the theoretical mean maximum distance of sex pheromone communication between the males and females of the cabbage looper. Estimates of communication distance decreased with an increase in wind speed. The optimum wind velocity was 2.5 cm/sec. The maximum communication distance was estimated at 200 m. The theoretical maximum distance was based on: (1) emission rate of pheromone from females, (2) dilution of pheromone molecules in moving air, and (3) the lower threshold for male pheromone-responsiveness. This distance was further limited by the duration of pheromone emission by females and the flight speed of males, both varying with wind velocity. The females emitted no pheromone on nights when the wind velocity was very low (0 cm/sec) or very high (300 cm/sec). The female emitted pheromone longer, continuously, at lower wind velocities.

Formula: $$X = \frac{vt\ (r-v)}{r}$$

X = communication distance (cm)

t = time female spends continuously emitting pheromone (sec)

r = male air speed (cm/sec)

v = wind velocity (cm/sec)

The Japanese beetle has been visually tracked 18 m upwind to confined females (Ladd, 1970). Cuthbert and Reid (1964) observed that sex pheromones released by the banded cucumber beetle, Diabrotica balteata, attracted the males from a distance up to 15 m.

The importance of trap design in the efficiency of a trapping system was demonstrated by Sharma et al. (1971a), Sharma et al. (1971b), Butt (1974), Sharma et al. (1973), Kennedy (1975), Kaae and Shorey (1972b), Holbrook et al. (1960), Ladd et al. (1973), McMillian and Borden (1974), AliNiazee and Stafford (1973), Dickerson and Hoffman (1977), Yonce et al. (1976), Jacobson (1965), Hollingsworth et al. (1978).

Sharma et al. (1971a) found that at a given pheromone release rate, the trapping efficiency must depend on trap design and not the number of males stimulated to orient towards the trap. The studies were conducted with the pink bollworm males on sticky traps.

Kennedy (1975) evaluated eight trap designs for their effectiveness in capturing male potato tuberworm moths, Phthorimaea operculella. Trap design orientation by the males was also studied. A Pherocon 1 C trap caught significantly more males than the other designs. No explanation was given for the increase in trap effectiveness for the Pherocon 1 C trap.

Sharma et al. (1973) used several types of traps to evaluate the capture of male pink bollworms. An enclosed omnidirectional trap with a flat trapping surface and 8 side openings, for moth entry, caught more male pink bollworms than a similar trap with 2 openings and 4 other trap designs. A 6-fold increase of the optimum trapping surface of the omnidirectional trap caused a reduction in the capture of males. The increased trap catch on the omnidirectional trap was probably due to an optimum release rate of hexalure (synthetic sex attractant) due to an increased airflow through the trap with 8 openings.

Sharma et al. (1971b) worked with the evaluation of pheromone traps for males of the cabbage looper, Trichoplusia ni. Three trap designs were evaluated by Sharma. The hypothesis obtained stated that males orient toward the pheromone source as long as the situation is behaviorally "correct". When the situation is incorrect, as when a female is not located by the searching male at an appropriately high pheromone concentration, a behavior ensues that causes the male to leave the area. This behavior may be based on visual orientation to the lightest visual sector. In nature, this might be out through the foliage of a tree; near a light trap it might be toward the light;

and in the double cone trap it might be up through the large central screen cone and toward the light of night sky.

Kaae and Shorey (1972b) observed that only 15 to 25% of cabbage looper males were caught that actually did fly to it. The double cone trap was modified to increase its efficiency. The modifications were based on field observations of the behavior of the cabbage looper males orienting to and entering the pheromone-baited traps, and their movements after entering the traps. The major modification that improved the efficiency of the double-cone trap was removal of all visible barriers that appeared to hinder or prevent males from entering the body of the trap. Many males that approached the original double-cone trap hovered approximately 100-500 cm in front of the screen-cone openings. Most of the moths did not move any closer and left the general area after a short period. When the screen cones were removed and larger rectangular openings were cut around the base of the trap the males entered readily. Variations in trap entrance did affect moth captures with the cabbage looper. The size of trap openings were also important with the gypsy moth (Holbrook 1960). The amount of lure volatilized also depends on the size of the opening. Increased trap size with a greater adhesive-covered area also caught more moths. The position of the pheromone bait on the trap had little effect on the number of moths caught on the original Graham trap. Trap color had little effect on trap catch. The frequency of reapplying adhesive to traps showed that as the frequency of reapplication increased, the catching efficiency increased.

Pheromone wicks which were protected from the sun and rain remained attractive to the cabbage looper and codling moth males for longer periods (Butt et al., 1974, and Kaae and Shorey, 1972b). A plexiglass top, replaced with a screen top, on a double-cone trap, eliminated the orientation of attracted male moths to pheromone escaping from the top of the trap, which increased the trap catch.

Two trap designs were used to compare trap catch effectiveness with the larch casebearer, Coleophora laricella by McMillian and Borden (1974). A cylindrical trap was hung horizontally from a tree. The white cardboard carton, 19 cm long and 13 cm in diameter, had the upper half of each end removed and the interior trap surface 668 cm^2 coated with Stikem Special®. A flat trap with vertical pieces of white cardboard, 38 x 13 cm, and a surface of 448 cm^2, had both sides coated with Stikem Special®. The cylindrical traps were most effective, catching 3.43 times the number of males caught in flat traps and 2.30 times when a correction to equalize trap surface area was applied.

Dickerson and Hoffman (1977) found that a synthetic cabbage looper sex pheromone trap caught 5 times more male moths in a water-pheromone trap than a BL (black lighted) trap baited with cabbage looper pheromone and 36 times more than a BL trap alone. An increase in diameter of the water-pheromone traps caught 2 times more cabbage loopers on a 41-cm diameter trap than a 23-cm diameter trap.

Male Japanese beetles, Popilia japonica, were most attracted to yellow traps. Yellow had an attractiveness rating of 100 as opposed to 97 for red, 88 for black, 67 for green and 57 for blue (Ladd et al., 1973).

AliNiaze and Stafford (1973) observed that low population levels of the grape leaf folder, _Desmia funeralis,_ are commonly passed unnoticed by many population-detection techniques. With increased trap design effectiveness, low population levels were detected by sex pheromone traps.

Trap location influenced trap catch of the pink bollworm moths in cotton fields (Sharma et al., 1971a). Traps placed in the border of the cotton field caught far fewer moths than traps in the center of the field.

Trap height was clearly a factor influencing trap catch for the pink bollworm moth (Sharma et al., 1971a). Traps placed at 1.2 - 1.8 m above ground caught more moths than at 0.6 and 2.7 m above ground. Traps placed at canopy height (1.2 - 1.8 m) had less hindrance of vegetation and the attractant dispersed over a larger area, drawing more moths to the traps.

Kennedy (1975) observed greater numbers of tuberworm moths, _Phthorimaea operculella,_ were captured at .3 m than at 1 m above ground. A Pherocon 1 C trap design was the most efficient design, independent of the heights tested.

Studies on the flight and distribution of the WCR by Witkowski et al. (1975) showed that males and females were active at the same time of day at a height below 1.84 m. Traps placed in corn fields showed the WCR flight heights to be as follows:

59% of beetles taken at .31 - .62 m,

32% of beetles taken at .92 - 1.22 m,

9% of beetles taken at 1.54 - 1.84 m.

Howe et al. (1963) placed vertical poles covered with adhesive into corn fields at .92 m, 1.84 m, 2.76 m and 3.68 m. The study conducted during late August showed that most NCR beetles were caught below 1.84 m.

Bartelt and Chiang (1977) indicated that traps placed at .3 m and .9 m were most effective. Traps placed at 2 m (tassel height) attracted very few beetles. This may be a result of increased pheromonal dispersion. The lower trap heights corresponded to corn ear tip heights.

Pheromone concentration studies were conducted with the cabbage looper by Sharma et al. (1971b). Results indicated that the males oriented toward the pheromone source as long as a threshold pheromone concentration was detected by the moth. If this dosage was not detected a behavioral reaction ensued which caused the male to leave the area (Shorey and Gaston, 1965). Shorey and Gaston (1970) showed that a variation in the numbers of males stimulated to orientate to a pheromone source, was associated with the pheromone quantity. Greater numbers of males oriented to larger quantities of pheromone.

An additive effect of pheromonal response was shown by Buriff et al. (1974) with the lesser peach tree borer. Buriff reported that traps baited with five females attracted five times as many beetles as traps baited with one female. A possible explanation would be that the females may call periodically, independent of the females in the same trap. An increase in the trap effectiveness of the traps containing numerous females would be a result of longer pheromonal emission times.

Yonce et al. (1976) indicated that with each 10-fold increase in the concentration of synthetic pheromone from 10 ug/trap to 10,000 ug/trap there was significantly greater numbers of lesser peach tree borers attracted. Research with other insects has shown similar results.

Field tests conducted by Ball and Chaudhury (1973) indicated that the WCR beetle response to pheromone-baited traps increased almost directly with FE's (Female equivalents) present. An active response did not occur until 500-1500 FE's was used to bait traps. Ball determined that small amounts of pheromone are stored in the WCR female. Only 5 ug was extracted from the abdominal tips of 37,500 WCR females.

Cuthbert and Reid (1964) showed a variable response by the banded cucumber beetle to pheromone extracts of known female equivalents. A 10-female equivalent of the abdominal extract was almost 2.5 times as attractive as a virgin female the first 24 hours. A one female equivalent extract was almost one-third as attractive as a virgin female. The study indicated that the filter papers steadily lost the extract. By the third day the 10-female equivalent was only half as effective as a virgin female and the one female equivalent was only a fifth as effective.

Maitlen et al. (1976) worked with aged pheromones of the codling moth. Tests showed that a pheromone sample that initially contained 1.5 mg of pheromone contained only .75 mg after 26.5 days (half-life). This may explain the reduced attractiveness of the pheromone in this field test and in other similar field tests with other insect pests.

Berger et al. (1964) determined that 100 female equivalent baited traps attracted greater numbers of male pink bollworms than traps baited with 10 female equivalents for the first 4 to 5 days. After only five days the attractant lost its effectiveness. Traps baited with 10 female equivalents were effective for only a day or two. The crude extracts were obtained from 4-5 day old female abdominal tips. The reduced trap catch in these field tests may have been due to an aged pheromone factor. This may explain the lowered pheromonal attractiveness with longer periods of continuous exposure of the pheromone extract.

Bartelt and Chiang (1977) used a multiple regression analysis in an attempt to relate CRW pheromone extract trap catches to various environmental factors. The factors studied included the following: temperature (°C), wind speed (m/sec), solar radiation intensity terms, dew point depression (°C), and the population densities of the NCR and WCR males. The environmental factors explained 73% of the variability in the trap catch means for the NCR and 64.8% for the WCR. All environmental factors analyzed did significantly influence trap catches at various levels. Only about one-third of the trap catch variability in the means were still unaccounted for. The competition from female beetles and their effect on male behavior toward the pheromone extract traps, and other factors, may have contributed to the remaining trap catch variability.

Guss (1976) investigated various environmental factor effects on trap catch variability of the CRW on pheromone baited sticky traps. Guss showed that low temperatures over the collection period (<10°C) may have caused a decrease in trap catch of the WCR. Witkowski et al. (1975) noted that temperatures below 15°C during the night and day reduced the flight activity of the CRW. Also, when early morning temperatures dipped below 22.2°C, the individual activity peaks shifted toward the warmer later morning or afternoon hours. Bartelt and Chiang (1977) observed trap catches for the NCR and WCR increased with temperature to 26.5°C and decreased above that level. Cuthbert and Reid (1964) determined a decrease in activity of the banded cucumber beetle male and female occurred at temperatures less than 18°C.

The temperatures at which certain species of insects respond to sex pheromones emitted from the potential mating partner have been found to fall in narrow temperature bands. The temperature ranges in which optimal pheromonal responsiveness occur would be expected to be different for each insect species. For instance, the male gypsy moth which mates only in daylight, never responds to a female sex pheromone source at temperatures below 21°C in the field. The males did approach the pheromone sources in increasing numbers as the temperature rose to 32°C (Collins and Potts, 1932).

Klun (1968) showed European corn borer male moths gave greater response to the female sex pheromone extracts at 20-23°C than at 27°C. Cool temperatures during the dark hours were more conducive to mating than warmer temperatures. The optimal pheromone release occurred in the same range of temperatures that are conducive to pheromonal responsiveness to the opposite sex. This show that temperature is an important environmental factor which influences the response of insects to pheromone sources.

Showers et al. (1974) concluded that overnight temperature plateaus influenced the trap catch of the European corn borer. Nights without at least one 2-hour period of constant temperature caused lower male trap catches on sex-pheromone baited traps.

Gentry and Davis (1973) reported that higher air temperatures contributed to a higher rate of evaporation of synthesized cabbage looper pheromone. This higher rate of evaporation may contribute to increased trap catches. Sower et al. (1971) stated that 12°C was the optimum pheromone release temperature for the female and for greatest pheromonal male responses. This indicated the narrow bands of optimal temperature for insect reproduction.

Wind velocity was shown by Kaae and Shorey (1973) to be an important environmental factor affecting the communication distance for the pink bollworm. The sex pheromone was emitted at various elevations in the cotton field foliage depending on the wind velocity. High winds disrupt the sex pheromone communication (Sower et al., 1973) and impair male and female flight at canopy height. On calm nights (0-3 mph) the males approached the females near the foliage canopy and on windy nights near the ground level.

Kaae and Shorey (1972a) determined wind velocities between .3-1.0 m/sec were most conducive for the cabbage looper female to release the sex pheromone. Wind velocities below .1 m/sec and above 4 m/sec were less conducive to pheromonal communication. The males became disoriented and their ability to find the pheromone source was severely inhibited. A corresponding decrease in pheromonal release time was evident in these low and high wind velocities. Gentry and Davis (1973) stated the increased air movements, within limits, caused greater dissemination of the pheromone which contributed to increased trap catches.

Showers et al. (1974) showed that wind direction parallel to the North-South series of traps caused increased trap catches on down-wind traps for the European corn borer. Winds across the trap series axis caused the trap catches to be more evenly distributed. Therefore, wind direction with respect to the placement of traps would be an important consideration in the design of a field test.

Bartelt and Chiang (1977) concluded that the trap catches for both the NCR and WCR increased with rising wind on pheromone extract traps. Trap catches were poor on calm days. Guss (1976) observed that a consistent wind speed around 4.5 m/sec., with daytime temperatures at 30°C and a high RH (85%) did increase trap catch. Precipitation decreased trap catch of both NCR and WCR species.

Daily fluctuations in certain environmental factors such as light intensity may control daily timing of pheromone activity by phase-setting circadian rhythms. Light intensity which varies between > 100,000 lux at mid day and < 0.01 lux on a moonless night, is one of the most predictable environmental factors that fluctuate on a daily basis. Light intensity is a major factor controlling whether insect sex pheromone activity will occur and the intensity at which it may occur as suggested by Bartell and Shorey (1969). A male insect that typically mates at dusk, the light-brown apple moth, <u>Epiphyas postvittana</u> (Walker), had suppressed responsiveness to the female sex pheromone at light intensities greater than 3.5 lux. The cabbage looper moth mates during the hours of darkness (Shorey and Gaston, 1964). Light intensities greater than the equivalent to full moonlight (0.3 lux) inhibited male responses to female sex pheromones. A 10,000 fold increase in pheromone concentration was required at a light intensity of 30 lux to stimulate males to exhibit similar levels of responsiveness achieved at .3 lux. Saario et al. (1970) showed that male cabbage loopers were attracted to pheromone-emitting traps in the field as readily on nights which had a full moon as they were on nights which had no moonlight (< 0.01 lux).

Sower et al. (1970) observed cabbage looper females everted their glands and released pheromone more readily with increasing darkness. The maximum pheromonal release behavior occurred at .3 lux light intensity which appeared to be most suitable for male responsiveness. Little work has been conducted on the control of sex pheromone release by light intensity.

Bartelt and Chiang (1977) studied solar radiation intensity relationships with trap catch variability of the WCR and NCR. The WCR was most active during periods with light intensities lower than 0.3 cal/cm^2 sec. The WCR was trapped at any time of day as the light preference was not well marked. The NCR was most active in total darkness and activity dropped off very sharply as the light intensity increased. The solar radiation intensity accounted for 50% of the NCR trap catch variability.

The cabbage looper (Saario et al., 1970) and the pink bollworm (Sharma et al., 1971a males approached pheromone-baited traps at midnight in mid-summer and early-evening by October. There was a seasonal shift in pheromonal release by the females and pheromonal responsiveness by the males for both insect species.

Sower et al. (1971) evaluated the interaction of temperature and light:dark periodicity on the pheromone release time by the cabbage looper females. At cooler temperatures the females released the pheromone earlier in the dark period as the season progressed. This forward shift in pheromonal communication behavior timing to earlier in the evening would be a selective adaptive advantage for an insect. The same level of pheromonal responsiveness would be maintained with the progression of the mating season.

Bastiste et al. (1973) determined the codling moth had a clearly patterned daily rhythmicity with a light:dark cycle. As the mating season progressed, the males responded to the pheromone source later in the evening. A synthetic pheromone (codlemone), which was released throughout the day, was compared to the trap catches obtained with female-baited traps. The males had a similar patterned response to both baited traps in essentially the same rhythmic fashion. This indicated that the pheromone communication between the two sexes coincided with the light:dark cycle.

The codling moth daily response to the sex pheromone had a tendency to shift later in the evening as the season progressed (Bastiste, 1970). The flight response to the pheromone was influenced by temperature. No response was observed below 16°C to the pheromone source.

The female banded cucumber beetle was determined to release a sex pheromone almost continuously by Cuthbert and Reid (1964). Again temperatures at or below 18°C caused the males and females to become inactive and little pheromonal response was indicated.

Bartelt and Chiang (1977) could not demonstrate any daily emission patterns with the WCR female from hourly trap collections. The female-baited trap and the pheromone extract trap catch comparisons indicated there were no emission pattern. Both traps attracted beetles in similar patterns. The similar activity peaks suggested that the male may be controlled by the female sex pheromone emissions to an unknown degree. The WCR was most active before sunset and again after sunrise, exhibiting a bimodal response pattern. Witkowski et al. (1975) and Guss (1976) indicated a similar daily response pattern for the WCR. The NCR was determined to be most active during the hours of darkness by Guss (1976) and Bartelt and Chiang (1977). Guss showed the male NCR beetle pheromonal response was rigidly controlled by the time-of-day. From trap collections taken twice daily at 0900 hours (CDT) and 2030 hours (CDT), Guss observed significant NCR male beetle numbers on the extract-baited traps only during the morning collection. The NCR male beetles were practically absent from the evening collection. Bartelt and Chiang (1977) concluded further that the NCR was most active around midnight from trap collections taken every two hours over a 5-day study period. The daytime hours between 0530 and 1600 hours (CDT), were designated as non-peak hours for their limited response in terms of trap catch numbers.

Shorey et al. (1968) stated that pheromone responsiveness, production, and release matures and becomes operative in insects at characteristic ages. Pheromonal communication was closely correlated with the maturation of these pheromone related processes in an insect.

Cuthbert and Reid (1964) working with the banded cucumber beetle, showed that 78% of the 5-9 day old males and 93% of the 5-14 day old males were attracted to a baited-sticky trap within a screened cage with dimensions of 3.67 m x 3.67 m.

Bartelt and Chiang (1977) determined that the virgin female would need to be about 3-4 days old before becoming attractive. Guss (1976) observed the WCR male age response to virgin female sex pheromone extracts. The age response of the WCR males were as follows:

Male Age	% Response
0 - 1 days	0%
1 - 2 days	10%
2 - 3 days	31%
3 - 5 days	55%
5 - 7 days	80%
7 - 9 days	95%
23 - 31 days	87%
38 - 49 days	88%

This data illustrated the need for a certain amount of maturation by the WCR male before consistent responses to a laboratory bioassay can be expected. Seven days after adult emergence an 80% response can be obtained, and continued for up to seven weeks post-emergence. The data indicates that maturation of the male pheromonal response system is somewhat variable. The initial peak of maximum pheromonal responsiveness occurred at the 7-9 day range.

Bartelt and Chiang (1977) and Guss (1976) indicated that within a short time after mating (1 day), the female was not attractive to males of either the NCR or WCR species.

The potential use of sex pheromones in survey and control programs has received considerable attention in recent years with many economic pest species. Studies with sex pheromones in survey and control programs have been evaluated for their effectiveness: AliNiazee (1976), Beroza et al. (1971b), Beroza (1976), Beroza et al. (1974), Beroza and Knipling (1972), Davis et al. (1973), Doane and Carde' (1973), Gaston et al. (1977), Farkas et al. (1975), Jacobson and Beroza (1964), Kaae and Shorey (1973), Madsen and Vakenti (1972), Maitlen et al. (1976), McMillian and Borden (1974), Osmani (1970), Shorey et al. (1967), Shorey et al. (1972), Shorey et al. (1974), Sower et al. (1973), Taschenberg et al. (1974), Trammel et al. (1974) and Wong et al. (1972).

Jacobson and Beroza (1964) stated that sex pheromones used in surveys could detect an early infestation making it possible to eliminate the population before there would be a chance to spread. The detection of economic damaging pest species would be beneficial if detected early to reduce chemical treatments.

Beroza (1976) reported that sex pheromones are known for some 35 insect species of economic importance. The use of pheromone-baited traps for estimating field populations can be misleading under the assumption that trap catches are proportional to the field population of the insect. In field tests conducted the pheromone emission rate was high at first. It decreased rapidly and gradually diminished over a prolonged period. Unreliable estimates would be obtained based on the emission rates that change with exposure time. A wick that emits pheromone at a constant rate would be necessary to increase reliable monitoring techniques.

The codling moth sex pheromone was used by Maitlen et al. (1976) and Madsen and Vakenti (1972) for population surveys. Maitlen determined that a release rate of 1.25 ul per hour produced the highest trap catches in field tests. Maitlen suggested the use of 5 mg of attractant per trap for surveys. The 5 mg attractant was found to be more attractive than a 10-female equivilent survey bait after as much as 4.4 months of 5 half-lives. Madsen and Vakenti indicated that codling moth pheromone traps were useful for estimating natural populations and for determining the need for chemical control.

Bartelt and Chiang (1977) discussed several considerations for using pheromone traps to survey populations. The results obtained in their studies indicated the possible use of pheromones to monitor field populations of the CRW. Increased precision could be obtained by the placement of traps within a meter of the ground and by adjusting for environmental factors such as temperature, atmospheric moisture and wind speed.

With respect to control procedures Birch (1974) stated that the pheromone communication system is a potentially vulnerable point in the life cycle of economic pest species. Birch discussed three communication disruption methods which can alter or prevent mating. First, mass trapping consists of luring, male insects into an artificial source of pheromone and removing the males from the field population prior to mating. Second, a confusion method involves the saturation of the atmosphere with enough pheromone to prevent male orientation to any specific pheromone source, trap or female. Third, a habituation method involves exposing the males to a pheromone permeated atmosphere. Once the males react to this stimulus, further response to a pheromone source is suppressed for some time thereafter. A constant or repetitive stimulation lowered an insect's responsiveness. A sensory adaption or fatigue decreased the tendency of the male insect to respond to a definite pheromone source. The interference with the insects ability to perceive a pheromone would make possible these applications for control.

Birch (1974) stated that the evaluation of pheromone test effectiveness involved many complicating factors. In the suppression of an insect pest population, it is not enough to count the number of insects trapped as indicative of the efficacy of the control method. Independent estimates are necessary on the percentage mortality caused by the treatment on the field population. Life tables should be available to evaluate the percentage mortality which will have a significant effect on future population levels.

The most successful and rapid eradication was made with the control of the Mediterranean fruit fly from a million acres in Florida during 1956 and 1957 (Jacobson and Beroza, 1964, Beroza, 1971 and Osmani, 1970) at a cost of $11 million. The main difficulty with this type of control program would be the obtaining of large enough quantities of the synthetic or pure pheromone substances to carry out the control program. For example, only 20 mg of the pure active pheromone was extracted from the abdominal tips of 500,000 female gypsy moths (Jacobson and Beroza, 1964).

The gypsy moth synthetic pheromone, disparlure, was used in a large scale disruption method for the control of 62 square kilometers naturally infested forested ha (Beroza, 1976). About 2 g of disparlure was applied by air to each acre. The method was evaluated by comparisons between trap catches obtained in treated versus untreated areas. The trap catches obtained on female-baited traps were 97-100 percent less in treated areas. This air-permeation method indicated the potential for pheromones as a direct control method for economic damaging insect pest species. Beroza et al. (1971b) and Jacobson (1965) indicated there may be a definite relationship between moth capture and the sex attractant dosage used for estimating gypsy moth populations and for classifying the degree of infestation by the numbers of moths captured on pheromone-baited traps.

Beroza and Knipling (1972) and Beroza et al. (1974) indicated that suppression of gypsy moth populations would be possible by the combination of applying insecticide to larvae emerging in the spring and distributing disparlure microcapsules during the mating season to prevent pheromonal communication. The air-permeation method would become progressively more efficient as the population was reduced. Comparable to the sterile-male release technique, the air permeation method would be capable of eliminating isolated populations of gypsy moths (Beroza, 1971, Beroza et al., 1971a, Beroza et al., 1971b).

Beroza et al. (1971a) estimated the female equivalent of disparlure to be 1-6 ug in a 5 mg triactanoin carrier. Beroza showed that small amounts of disparlure on traps were capable of attracting as many or more males than a live virgin female used to bait traps. This finding provides a basis to estimate the efficiency and practical potential of disparlure-baited traps.

Doane and Carde' (1973) evaluated the competition of gypsy moth males at a sex-pheromone source. The competitive behavior among males may insure dispersal of males from areas of heavy density. This would increase the probability of mating females in the surrounding sparse population areas where the reproductive potential of females is high. This selective advantage should be considered in the design of any male trapping study or pheromonal disruption method of communication.

Shorey et al. (1967) conducted experiments with the effective pheromone concentration necessary for the control of cabbage looper. They determined that a pheromone concentration of roughly $1\text{-}10^{-10}$ g/l would be sufficient to prevent the orientation of males to pheromone-emitting females. The tests conducted suggested that less than .5 g/ha must be expended each night for a large-scale cabbage looper mating control. The minimum effective pheromone concentration for male inhibition over wide areas in a behavioral control program for the cabbage looper depended on the determination of: (1) the release rate of pheromone from normal females, (2) the threshold concentration required to cause male orientation and the effective distances over which they will orient, (3) the possibility that localized areas exist at which both sexes aggregate before normal pheromone communication takes place, (4) flight ranges and migration characteristics of males and females, and (5) the influence of environmental conditions on sex pheromone communication behavior.

Shorey et al. (1972) suggested that disruption above 90% could be obtained in large plots with the cabbage looper. This could be obtained with less than 1 mg of looplure/ha per night at a cost of \$.001 to \$.002 per mg. A range from 10 to 100 mg per ha per night would achieve consistent disruption above 98%. The male:female disruption of communication appeared independent of moth population densities. Weather condition effects on the pheromone communication system were not known.

A high degree of habituation and an extremely slow recovery rate are important factors in programs utilizing atmospheric permeation as a means of pheromonal disruption (Farkas et al., 1975). They also suggested that pheromonal disruption of mating in natural populations of the cabbage looper would depend on confusion rather than habituation. Studies showed that males would respond repeatedly to intermittent pulses of pheromone over prolonged time periods without becoming completely habituated.

The disruption of pheromonal communication of the pink bollworm was studied by Shorey et al. (1974) and Gaston et al. (1977). Shorey determined that disruption of the premating pheromonal communication between the male and female pink bollworm resulted in a reduction of larval boll infestations comparable to that provided by commercial insecticide applications. Gaston determined there was a 9-fold reduction of insecticide usage in pheromone treated fields. The larval control was comparable to the control achieved by conventional insecticide applications in terms of effectiveness and the expense of materials used.

Wong et al. (1972) evaluated the mass trapping or confusion method on the lesser peach tree borer. They determined that 90% or more of the males would need to be captured during the first mating flight to suppress a high degree of reproduction. The proportion of emerging males which would be captured in their first mating attempt depends on the ratio of attraction by females in baited traps and the attraction of the competing virgin females in the field population. The effectiveness of large scale mass trapping procedures may be evaluated by comparing population counts the following year versus the counts of borers the previous year. A reduced native borer population would increase the attractant power of the female-baited traps.

Mass trapping of male red-banded leaf roller moths was conducted by Trammel et al. (1974) and Taschenberg et al. (1974) with pheromone-baited traps. Results were very similar in both test procedures. There was almost a total disruption of male orientation to the sex attractant from the pheromone emitting females in the field and the female baited traps. There was a substantial reduction in crop damage in both disruption procedures. The general conclusion derived by Taschenberg stated that disruption by habituation would require lower quantities of attractant and would be effective regardless of the number of calling females in the test area. The minimum trap density for mass trapping techniques needs further evaluation. The control procedure would be further enhanced if control techniques were developed to disrupt pheromonal communication for several insect species to a single trap.

McMillian and Borden (1974) observed a strong pheromonal response with the larch casebearer, Coleophora laricella, males. The tests suggested that a mass trapping or confusion control program may be possible if large enough quantities of synthetic pheromone become available. Mass trapping this insect could be very effective, for the larch casebearer males are relatively weak flyers and would be retained within a target area. The studies also suggested the potential of pheromone traps in monitoring the effectiveness of bio-control programs.

AliNiazee (1976) evaluated mass-trapping techniques with the filbert leaf roller, Archips rosanus. The pheromone trap effectiveness indicated the possible use in direct suppression of the adults. The pheromone traps were of little value in determining the proper timing of insecticide application or in predicting the current year's larval populations or damage potential. Traps may be used to predict treatments for the following year.

Suppression of yellowjackets, Vespula pennsylvanica, in fruit orchards was possible with almost no contamination of the environment (Davis et al., 1973). Due to the attractants high specificity, little or no effect on the beneficial insect species was observed. This would be an important aspect of any pheromone-based pest management program.

Survey and control procedures with the insects mentioned and numerous others offer evidence for the use of pure and synthetic sex pheromones for monitoring and controlling field populations of insects. Further research with respect to insect behavior, mating habits, and response of insects to specific pheromone sources are necessary for economic damaging pest species. Trapping techniques need further research to understand their influence on an insect's behavioral response to a pheromone trap: trap design, trap height, trap color, trap size, trap location, pheromone age and concentration or dosage. Environmental factors also affect the insect's response to a pheromone trap: temperature, wind speed, relative humidity, dew point depression, atmospheric moisture, solar radiation intensity, and population density. Insight into the underlying factors which influence or control an insect's response to a pheromone source are essential to improve survey or control procedures. It is unlikely that an insect field population will become resistant or immune to pheromonal disruption methods as they have to insecticides.

The potential in survey and control of insect field populations involves many complicating factors. Once economic damage threshold levels for pest species are established on the basis of pheromone-baited trap counts, such monitoring techniques can be effectively used in timing control procedures.

III. MATERIALS AND METHODS

Corn rootworm sex pheromone field-trapping studies were initiated in South Dakota during late June and continued through July and August in 1976 and 1977. The field sites were located in Turner and Brookings Counties in 1976 and in Brookings County during 1977. Because of drought conditions in 1976 the fields selected in Turner County were fields which had been irrigated.

Dr. Paul Guss, Research Biochemist, Northern Grain Insects Research Laboratory, USDA, Brookings, South Dakota, provided the WCR pheromone stock solution. Guss (Personal Communication) estimated the 50 ul stock solution contained 20-25 ng pure pheromone per ml. This estimate was based on fields tests comparing beetle trap-catch numbers between the stock solution and a 4-4.5 ng pure pheromone concentration during August, 1977.

The WCR pheromone stock solution was prepared from a crude, unfractionated sample used in a 1:5 dilution with a triactanoin extender. The 50 ul per ml pheromone stock solution (20-25 ng pure pheromone per ml equivalent) was refrigerated in a glass stoppered 500 ml glass flask to inhibit volatilization of the active pheromone components.

The 50 ul pheromone stock solution was used to prepare the pheromone concentrations. Each dosage contained the ca. levels of pure pheromone: 50 ul, 20-25 ng; 35 ul, 14-17.5 ng; 25 ul, 10-12.5 ng; 15 ul, 6-715 ng; 5 ul, 2-2.5 ng; and 2.5 ui, 1-1.25 ng. The pheromone dilution process required the following materials: dental cotton wicks (3.5 cm in length); disposable petri dishes (150 x 15 mm);

disposable 1 ml pipettes; cork-stoppered test tubes (10 x 75 mm); tape; and marker. The desired pheromone dosage level was pipetted onto the dental cotton wick. The wick was sealed in a marked petri dish with tape for transport to field evaluation sites.

Two trap designs were evaluated in this study. A white cylindrical cardboard ice cream carton (16.9 x 8.6 cm) trap design (Fig. 1) with 480 cm^2 of the outer surface area coated with Stickem Special® adhesive and a Pherocon II trap design (Fig. 2) commercially manufactured by Zoecon, was entirely coated with the Stikem Special® adhesive (10.0 x 15.2 cm per side), which covered 1030 cm^2 of the trap surface area.

Non-baited ice cream carton control traps (wicks treated with 1 ml of 10% of triactanoin extender) were placed at ear-tip height 18 m from the nearest pheromone-baited traps to measure attractancy of the trap design. The trap catches obtained indicated the random movement or activity level response of the CRW beetles.

The traps were mounted on wooden stakes (121 cm in length). The stakes were driven 16 cm into the ground within the corn rows, 18 m apart. Leaves were removed from the surrounding corn plants to prevent disturbance of the placed traps. The traps were adjusted either to ear-tip height (115 cm) or to canopy height (200-230 cm).

The pheromone wicks were secured to the top of the cylindrical trap with a pin and placed inside the Pherocon II trap on a petri dish (150 x 15 mm). This procedure prevented the wicks from contacting the adhesive on the traps. The stake was entirely coated with the adhesive (680 cm^2 surface area exposed) to ensure consistent, maximum capture of all beetles attracted to the pheromone-baited sticky traps.

In 1976, the Stikem Special® adhesive ran down the stakes. To keep the trapping surface constant in 1977, the stakes were entirely coated with adhesive. The trap and stake were recoated with the Stikem Special® adhesive every 3-5 days. Three factors influenced the thinning of the adhesive on the traps which caused some beetles to be lost. These factors included high temperatures, rainfall, and beetle collections. The high temperatures and rainfall caused the adhesive to run off the traps. Greater beetle numbers collected resulted in removing more adhesive from the traps with the beetles.

The traps were checked at 24-h intervals. The numbers of WCR and NCR beetles adhering to the trap and stake were removed and recorded from each baited and non-baited pheromone trap. The beetles were collected from the traps with a metal spatula and counted with a hand counter before being placed in vials containing a 100% hexane solution. The procedure facilitated species' identification and sexing of CRW beetles.

The CRW beetle field populations were tabulated by counting beetles on a total corn-plant basis from 50 randomly selected plants at least 10 m from the corn field border. These plant counts were taken in the trap site area prior to the placement of the pheromone-baited traps in the field. After a trap had been placed in the field, plant counts were obtained within 10-20 m of the nearest trap. The average 50 total-plant-counts were obtained and recorded on a beetle-per-plant basis (B/P) for each corn field used in this study. This procedure was repeated every 3-5 days within the fields where pheromone-trapping data were obtained.

Trapping procedures were analyzed statistically with a two-way analysis of variance and Duncan's new-multiple range test to determine the level of significance individual trap procedure methods had on daily trap-catch variability. The various trapping procedures involved the following: pheromone concentration response by beetles to ul of pheromone/ml extender; beetle response to field aged pheromones; trap design; and trap height effects on numbers of beetles collected.

A multiple regression analysis was conducted to evaluate the effect of environmental factors on NCR and WCR trap-catch variability. The daily NCR and WCR trap catches were regressed on three environmental factors over a 45-day study period: hourly readings of temperature (°C), wind speed average (m/sec), and relative humidity (%). The R^2 values obtained indicated the amount of daily trap-catch variability explained for the CRW beetles.

Correlations between beetle per plant (B/P) counts and trap catches were studied to evaluate the precision in which CRW beetle field populations may be monitored by daily pheromone-baited sticky trap collections. The R^2 values derived indicated the potential of this evaluation method for predicting CRW field populations on a B/P basis. Correlations between non-pheromone and pheromone-baited traps were made to determine the predictability of pheromone-baited trap catch numbers from the non-pheromone trap catch data.

IV. PROCEDURE

WCR pheromone-baited sticky traps were placed in 2 irrigated corn fields in Turner County in southeastern South Dakota, on June 29, 1976. The irrigated corn fields were selected because of the drought condition existing in the state during 1976. Four additional non-irrigated corn fields were studied in Brookings County, extreme east-central South Dakota, in August of 1976.

The WCR pheromone studies in 1976 provided the necessary background information which enhanced research in 1977. In 1976, daily fluctuations in CRW beetle trap catch were evident. This created interest for further studies in 1977 to possibly explain daily trap-catch variability of the CRW beetle. The major factors influencing trap collection numbers appeared to be related to the trapping procedure and environmental factors. The trapping procedure factors evaluated consisted of the following: trap design, trap height, pheromone exposure and pheromone concentration. Environmental factors evaluated included temperature (^{o}C), wind speed average (m/sec), and RH (%) readings taken at hourly intervals and beetle density on a B/P basis.

Pheromone-baited traps were placed in corn fields within Brookings County on June 28, 1977. Detection of initial emergence patterns of the NCR and WCR beetles were studied. The NCR beetle and WCR beetle were initially detected on June 29 and July 5, respectively. Pheromone-baited traps were placed in corn fields between July 19 and September 2, 1977, to evaluate trapping procedures and environmental factors on corn rootworm beetle catches.

Trap design and trap height studies were conducted to determine their effect on corn rootworm trap catch. The effectiveness of the ice cream carton trap and the Pherocon II trap were studied in two separate field tests. The two traps were baited with a maximum 50 ul WCR pheromone concentration level. The traps were placed at ear-tip height, 20 m from the corn field border and at 18 m intervals. Daily trap collections were taken between 1400 and 1500 h. In the trap-height field study, 2-50 ul pheromone-baited sticky traps were placed at ear-tip height and canopy height. The traps were placed 30 m from the corn field border at 18 m intervals. The study period started August 27 and ended on September 2, 1977. Daily trap collections were taken between 1400 and 1500 h.

Dr. William Lytle, Associate Professor of Agricultural Engineering, provided the weather data used in the multiple regression analysis on CRW daily trap catch variability. The weather data were collected from the roof of the Agricultural Engineering building, located on the South Dakota State University campus, in Brookings, South Dakota. The weather data was recorded 2 miles southeast of the field studied. The environmental factors studied included temperature (^{o}C), hourly wind speed average (m/sec), and RH (%). A 50 ul pheromone-baited ice cream carton trap, placed at ear-tip height and 25 m from the corn field border, was used in the study of daily trap catch variability with a multiple regresssion analysis. The daily trap collections were taken at 0830 h from July 19 to September 1, 1977. The NCR and WCR beetles were counted separately for individual regression analyses.

The effect of previous pheromone exposure on trapping data was analyzed at four individual corn field sites with ice cream carton traps placed at ear-tip height. Traps were placed 20-36 m from the corn field border with exposed 50 ul pheromone wicks. Trap catches were obtained between August 2 and September 2, 1977. Daily trap collections were taken between 9000 and 1400 h.

The influence of trapping procedure on corn rootworm trap catch means at several individual corn field test sites were evaluated with a two-way analysis of variance (pheromone dosage versus daily trap catch) and Duncan's new-multiple range test. CRW dosage response numbers were evaluated in several corn field tests. At one field location, the trap catch means were analyzed statistically from 4 pheromone-baited sticky traps placed in the corn field on July 19, 1977. The pheromone concentration levels evaluated included a 15 ul, 35 ul, 50 ul and a crude (1.5 ml) pheromone extract. Daily trap collections were taken at 0830 h. Two identical pheromone concentration series were placed in the same corn field on August 1 and August 16 for testing refinement of CRW dosage response.

The differences in pheromonal dosage responsiveness by the corn rootworm was further evaluated in 2 individual pheromone dilution series tests conducted from August 25 to September 2, 1977. Each pheromone dilution series consisted of 4 ice cream carton traps placed at ear-tip height with the following WCR pheromone concentration levels: 2.5 ul, 5 ul, 25 ul and 50 ul. The traps were placed 30.5 m from the corn field border and 18 m apart in these 2 field tests.

Daily CRW beetle collections were taken between 1000 and 1200 h in both tests.

Six field sites were evaluated for the influence of pheromone concentrations on daily trap-catch variability of the CRW. The effect of 25 ul and 50 ul pheromone concentration levels on trap catches were obtained between August 6 and September 2, 1977 utilizing ice cream carton traps placed at ear-tip height at 18 m intervals and 20 m from the corn field border. Daily trap collection times varied between 1000 and 1400 h at the 6 field location tests.

Three evaluation methods were conducted to determine the precision in which CRW field populations could be monitored using the WCR pheromone traps. In 1976, daily total trap catches were correlated with respective total corn plant (B/P) averages in 2 irrigated fields. Ice cream carton traps baited with 1.5 ml WCR crude-unfractionated pheromone were placed at canopy height 60 m from the corn field border.

Two different evaluation methods were analyzed in 1977 on corn rootworm trapping data. The first evaluation method compared the first-day trap catch with the B/P average taken prior to the placement of the pheromone trap in the field. This study involved dates ranging from August 2 to August 27, 1977. The second evaluation method conducted on the same 14 fields correlated pheromone-trap catch and B/P counts on 3 dates within each field test. The study period involved dates between August 2 and August 30, 1977.

V. RESULTS AND DISCUSSION

There are many complicating factors which are important to the design of a pheromone-based monitoring program. Trapping procedures and environmental factors affect daily trap catch variability. CRW pheromone trapping procedures were evaluated to determine their influence on trap catch data. The trapping procedures evaluated included trap design, trap height, length of pheromone field exposure and pheromone concentrations. The environmental factors evaluated included hourly variable readings of temperature (°C), wind speed average (m/sec) and RH (%). Beetle population levels, sex ratio and number of females emitting pheromone are additional biological factors that require elucidation.

A. Trap Design

The effect of trap design on trapping data may provide important criteria in designing future pheromone-based monitoring programs. In this study 2 trap designs were used: a cylindrical ice cream carton (Fig. 1) and a Pherocon II trap (Fig. 2). Bartelt and Chiang (1977) used 1 trap design: constructed from 9 x 15 cm pieces of 10-mesh hardware cloth. The upper surface of the trap cody was covered with aluminum foil which was coated with Tack Trap® adhesive. The under surface was not coated except for the outer edges. "Gutters" were present to retard dripping of the adhesive from the traps. The traps were baited with a caged female or a 1 ml stock solution extract. Both baits were hung beneath the trap body. Guss (1976) used one trap design: constructed with a horizontal 20.3 cm^2 piece of sheet metal

Fig. 1.-Ice cream container trap design.

Fig. 1.-Ice cream container trap design.

Fig. 2.-Pherocon II trap design.

Fig. 2.-Pherocon II trap design.

transversed by a 28.7 x 10.2 cm sheet in the vertical orientation. The entire metal surface was coated with Stikem Special®. A metal clip soldered to the top of the vertical metal sheet held a cotton wick to which the pheromone was applied. Trap designs have been evaluated for their differences in effectiveness with other insects. No published information has compared CRW beetle response to trap design.

The data analyzed with Duncan's new-multiple range test (Table 1) summarized the trap design effect on NCR beetle trap catch. The corn fields in which the traps were evaluated had populations of 95% NCR beetles. In field A and B, the Pherocon II trap design attracted consistently greater but not significantly different numbers of beetles than the ice cream carton trap design. In field A, the total NCR trap catches (trap and stake coated with adhesive) were significantly different, whereas in field B, no differences were detected. In both studies the NCR beetles adhering to only the ice cream carton and Pherocon II trap designs were lower in numbers, than those adhering to the stake. The beetles collected on the ground were included in the total NCR trap catch (trap and stake coated with adhesive). Unknown beetle numbers fell from both trap designs. The beetles adhering to the ice cream carton in another test (trap coated only) were one-third to one-half that caught with both the trap and stake coated with Stikem Special®. The surface area coated with adhesive was a major factor contributing to trap catch differences in this test. The overall test results showed inconclusive evidence in the

Table 1.-The effect of trap design on NCR male beetle trap catch on a WCR pheromone sticky trap (50 ul).[a]

Trap Design	Field A (Trap and Stake Coated)	Field A (Trap Coated Only)	Field B (Trap and Stake Coated)
Ice Cream Carton Trap	311.4 a	138.25 a	905.0 a
Pherocon II Trap	360.7 b	178.0 a	975.3 a

[a] Values within columns followed by the same letter are not significantly different at the 0.05 level by Duncan's new-multiple range test.

determination of trap design effect on beetle perception and pheromonal responsiveness as related to trap catch data.

B. Trap Height

Trap height has been shown to be an important factor influencing CRW pheromonal response differences. Bartelt and Chiang (1977) indicated that the trap height effect on CRW trap catch data was an important factor for the design of future pheromone-based monitoring programs. Traps placed at .3 and .9 m above ground level were very effective while traps placed at the 2 m level attracted very few beetles. Guss (1976) obtained good trap catches at 1.8 m (tassel height). Witkowski (1975) determined that 91% of the WCR beetles were attracted to non-baited vertical yellow sticky traps below 1.2 m. This indicated that most of the beetle activity occurred well below canopy height. This data provided evidence that a pheromone-baited trap placed at ear-tip height attracted greater numbers of beetles than a similar trap placed at tassel height. This may be due to the increased pheromonal dispersion at the ear-tip level where the beetles are most active.

This study analyzed statistically the trap catch differences between ear-tip and canopy height using a two-way analysis of variance. The trap catches were not significantly different between the two trap heights at the .05 level. The ear-tip and canopy height trap catches were as follows: August 27, 725 and 1203; August 28, 90 and 25; August 29, 523 and 260; August 30, 1330 and 267; August 31 203 and 91; September 1, 61 and 52; and September 2, 235 and 101. The

CRW collections were consistently greater at ear-tip height after the first day, but not significantly greater due to high daily trap catch variability. The greater CRW beetle response to ear-tip level traps may have been due to concentration of CRW beetles near the corn silks.

C. Environmental Factors (Temperature, Wind Speed and Relative Humidity)

The response of CRW beetles to a pheromone source is controlled by the time of day and changing weather conditions (Guss, 1976 and Bartelt and Chiang, 1977). Guss collected beetles from traps twice daily at 0930 and 2030 h. The NCR response to a WCR pheromone extract was indicated only during the 0930 h collection. Guss, and Bartelt and Chiang observed very few beetles responding to the pheromone-baited traps during the day-time-hours. The NCR male beetle response was greatest at 2400 h from observations by Bartelt and Chiang indicated a bimodal response pattern to the WCR pheromone baited traps. The WCR male beetles were most active 2-3 h before sunset and after sunrise.

Based on the research conducted by Guss (1976) and Bartelt and Chiang (1977) environmental factors were shown to influence daily trap catch variability. Bartelt and Chiang used multiple regression techniques to determine the influence of environmental factors on daily trap catch variability. The analyses explained 64.8% and 74% of the WCR and NCR trap catch variability, respectively.

Daily combined NCR and WCR trap catch data over a 45-day study period from July 19 to September 1, 1977 was studied with a multiple regression analysis. Only 42 of the 45 dates were included due to insufficient weather data on August 14, 22 and 29. Eleven hourly readings of 3 environmental factors were taken daily between 0500-0900 (early morning) and between 2000-0100 h (late evening). The 11 daily hourly readings include temperature (°C), wind speed average (m/sec), and RH(%). The time periods were selected on the assumption that the NCR and WCR daily response patterns to pheromone-baited traps were restricted to these active beetle time periods. The daily NCR and WCR trap collections were taken at 0830 h in a corn field with an estimated NCR and WCR field population ratio of approximately 50:50. The beetle per plant averages (50 total corn plant count average) ranged from .4 B/P on July 19 to a.5 B/P on September 1 over the 45-day study period. A total of 33 environmental variables were studied daily (11 temperature, wind speed, and RH readings). The multiple regression analysis of daily WCR and NCR beetle catches and the combined NCR and WCR trap catches were regressed on 33 environmental variables. The 42 trap collection dates with 33 daily environmental variables in the regression analysis limited the degrees of freedom to 8 with an F-test level of 5.32 (1,8) df.

<u>1</u>. <u>Western corn rootworm (45-day study period)</u>

The multiple regression analysis explained 58.9% of the WCR trap catch variability (Appendix A). Eleven environmental variable readings were significant: wind speed at 0100, 0700, 2000 and 2300 h; temperature at 0800 and 0900 h; and RH at 0100, 0800, 0900, 2100 and 2200 h, over the 45-day study period from July 19 to September 1, 1977. This is comparable with the 64.8% determined by Bartelt and

Chiang (1977). Their regression model (WCR) indicated that temperature and solar radiation intensity explained a high percentage of the variability in trap catch means. The calculated temperature optimum and solar radiation intensities were 26.5°C and 0.19 cal/cm^2 sec, with respect to calculated beetle activity. Witkowski et al. (1975) reported that the greatest beetle response to an unbaited yellow sticky-trap was near the upper level of the normal field temperature range. Bartelt and Chiang (1977) stated that trap activity increased as the WCR male population increased and as wind speed increased. Wind speed, temperature, and light intensity each accounted for ca. 20% of the variability when fitted into the regression analysis separately. Dew point depression and population density explained less trap catch variability.

2. Northern corn rootworm (45-day study period)

No significant environmental variables were determined by the multiple regression analysis for the NCR over the 45-day study period from July 19 to September 1, 1977. This analysis did not agree with the 73% determined by Bartelt and Chiang (1977). This may have been due to the additional environmental factors studied in their NCR multiple regression model: three solar radiation intensity terms, dew point depression and population density. Three solar radiation terms explained 50% of the NCR trap catch variability when studied separately. All other environmental factors explained only 16% of the NCR trap catch variability when the solar radiation terms were omitted.

3. Combined northern and western corn rootworm (45-day study period)

Daily total combined NCR and WCR trap catch data within the 45-day study period from July 19 to September 1, 1977, were studied with a multiple regression analysis. Only 1 environmental variable was significant. RH at 0900 h explained 12% of the daily trap catch variability. The prediction coefficient of 6.85 was positive with a constant of -167.29 (significant at the .05 level). The non-significant environmental daily hourly readings taken at 0500 and 0600 h were omitted in another multiple regression analysis approach. The hourly environmental variables were reduced from 33 to 27. No differences in results were obtained with WCR, NCR and total combined NCR and WCR trap catch variability.

4. Western corn rootworm regression analysis during early morning and late evening time periods (45-day study period)

The WCR daily trap catch variability was studied with a multiple regression analysis over a 45-day study period from July 19 to September 1, 1977. Daily WCR trap catches were regressed on hourly variable readings taken during 2 separate time periods: 0500-0900 h or 2000-0100 h. The results are summarized in Appendix B and C, respectively. The 0500-0900 h time period in Appendix B and C showed significant environmental variables to be wind speed at 0500 and 0700 h, and 0800 h; temperature at 0800 and 0900 h; and RH at 0500, 0800, and 0900 h. The 2000-0100 h time period in Appendix C had six significant environmental variables: wind speed at 0100, 2000, 2100 and 2300 h; and temperature at 0100 and 2300 h. This regression analysis approach showed that the combined hourly time periods (0500-0900 and 2000-0100 h) would be the more reliable periods for explaining WCR trap catch variability. This may be due to the bimodal response pattern of the WCR which has been shown by Bartelt and Chiang (1977) to occur in each of the 2 separate time periods studied (0500-0900 and 2000-0100 h). The separate analysis of the 0500-0900 h time period, R^2 = 44%, and the 2000-0100 h time period, R^2 = 27.7%, explained the lower WCR trap catch variability compared to the R^2 = 58.9% obtained in the combined daily separate time periods (0500-0900 h and 2000-0100 h).

Daily WCR trap catches were regressed on hourly variable readings taken during 3 separate time periods: 0700-0900 h or 2000-2200 h or 2300-0100 h. Five environmental variables were significant in the 0700-0900 time period: wind speed at 0800 h, RH at 0800 and 0900 h, and temperature at 0800 and 0900 h explained 28.4% of the WCR trap catch variability. Wind speed at 2000 h explained 10% of the WCR trap catch variability. Temperature at 2400 and 0100 explained 18.4% of the WCR trap catch variability. All listed variables were significant at the .05 level.

5. Northern corn rootworm regression analysis on early morning and late evening time periods (45-day study period)

The NCR daily trap catch variability was studied with a multiple regression analysis over a 45-day study period from July 19 to September 1, 1977. Daily NCR trap catches were regressed on hourly environmental variable readings taken during 2 separate time periods: 0500-0900 h or 2000-0100 h. RH at 0900 h explained 17.3% of the NCR trap catch variability. The prediction coefficient was a positive 5.94 with a constant of -212.61. Wind speed at 2300 h explained

14.7% of the NCR trap catch variability. The prediction coefficient of 28.7 was positive with a constant of 99.67. The lower trap catch variability percentages explained in these analyses indicate that temperature, wind speed, and RH were not dominant in this study of NCR catch data.

Daily NCR daily trap catches were regressed on hourly variable readings taken during 3 separate time periods: 0700-0900 h or 2000-2200 h or 2300-0100 h. The 0700-0900 time period had no significant variables. The wind speed at 2200 h explained 14.7% of the NCR trap catch variability. RH at 0100 h explained 17.3% of the NCR trap catch variability. All listed variables were significant at the .05 level.

As the season progressed the CRW beetle population increased from .4-2.5 beetles per plant (B/P) from July 19 through September 1, 1977. Three incremental study periods were analyzed within the 45-day study period. The study periods were evaluated to reduce the effects of changing beetle populations. This also reduced the effects of exposed pheromone variability within the 45-day study period. The 14-day, 15-day and 16-day incremental study periods began with the placement of a fresh 50 ul pheromone into the corn field on July 18, August 1 and August 16, 1977. The 3 study periods are represented in Fig. 3, 4 and 5.

The 3 daily time periods were evaluated in the NCR and WCR trap catch multiple regression analyses: 0700-0900 h, 2000-2200 h and 2300-0100 h. The daily NCR and WCR trap catches were regressed on 9 hourly variable readings in each regression analysis: 3 readings of temperature (°C), wind speed average (m/sec) and RH (%). The df were reduced to 4 or 5 in the separate regression analyses.

6. Northern and western corn rootworm regression analysis (July 19 to August 1, 1977)

The daily NCR and WCR beetle trap catch data shown in Fig. 3 from July 19 to August 1, 1977, were evaluated with a multiple regression analysis. The NCR regression analysis explained the following percentages of daily trap catch variability: 77.5% due to temperature at 0800 h and wind speed at 0900 h; 70% due to wind speed at 2000 h; 88.7% due to wind speed at 2300 h. The WCR regression analysis explained the following percentages of daily trap catch variability: 47.1% due to temperature at 0700 h; 71% due to wind speed at 2000 h; and 82% due to wind speed at 2300 h.

7. Northern and western corn rootworm regression analysis (August 2 to August 16, 1977)

The daily NCR and WCR beetle trap catch data shown in Fig. 4 from August 2 to August 16, 1977, were evaluated with a multiple regression analysis. The NCR regression analysis explained the following percentages of daily trap catch variability: 86.3% due to temperature at 0700 h and 0800 h, wind speed at 0700 h, and RH at 0900 h; the 2000-2200 h and 2300-0100 h time periods contained nonsignificant variables. The WCR regression analysis explained the following percentages of daily trap catch variability: 40.3% due to temperature and wind speed at 0100 h. The 2000-2200 h time period contained non-significant variables.

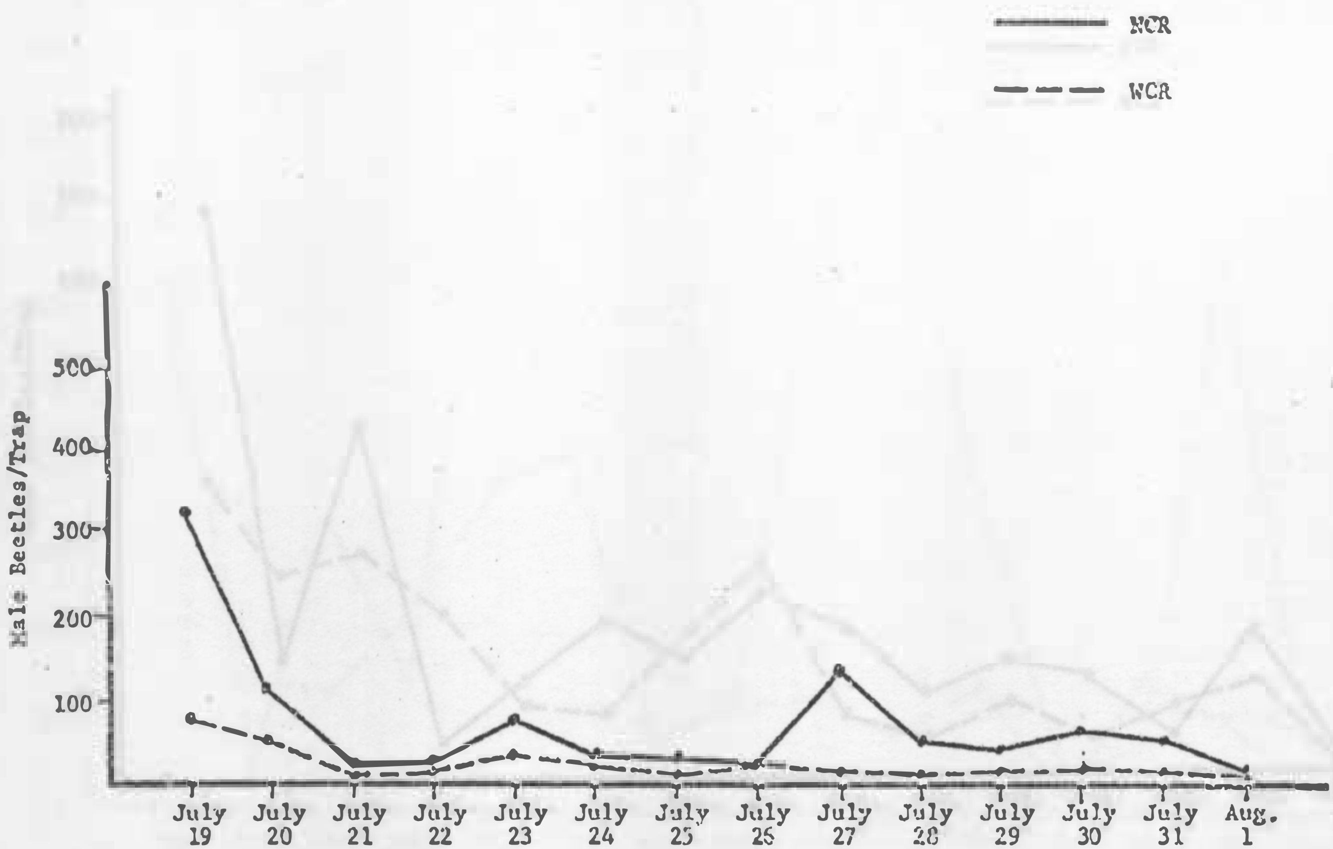

Fig. 3.-NCR and WCR males trapped in the field with 50 ul WCR pheromone concentration (Daily catch from July 19 to Aug. 1 at 0830 CDT).

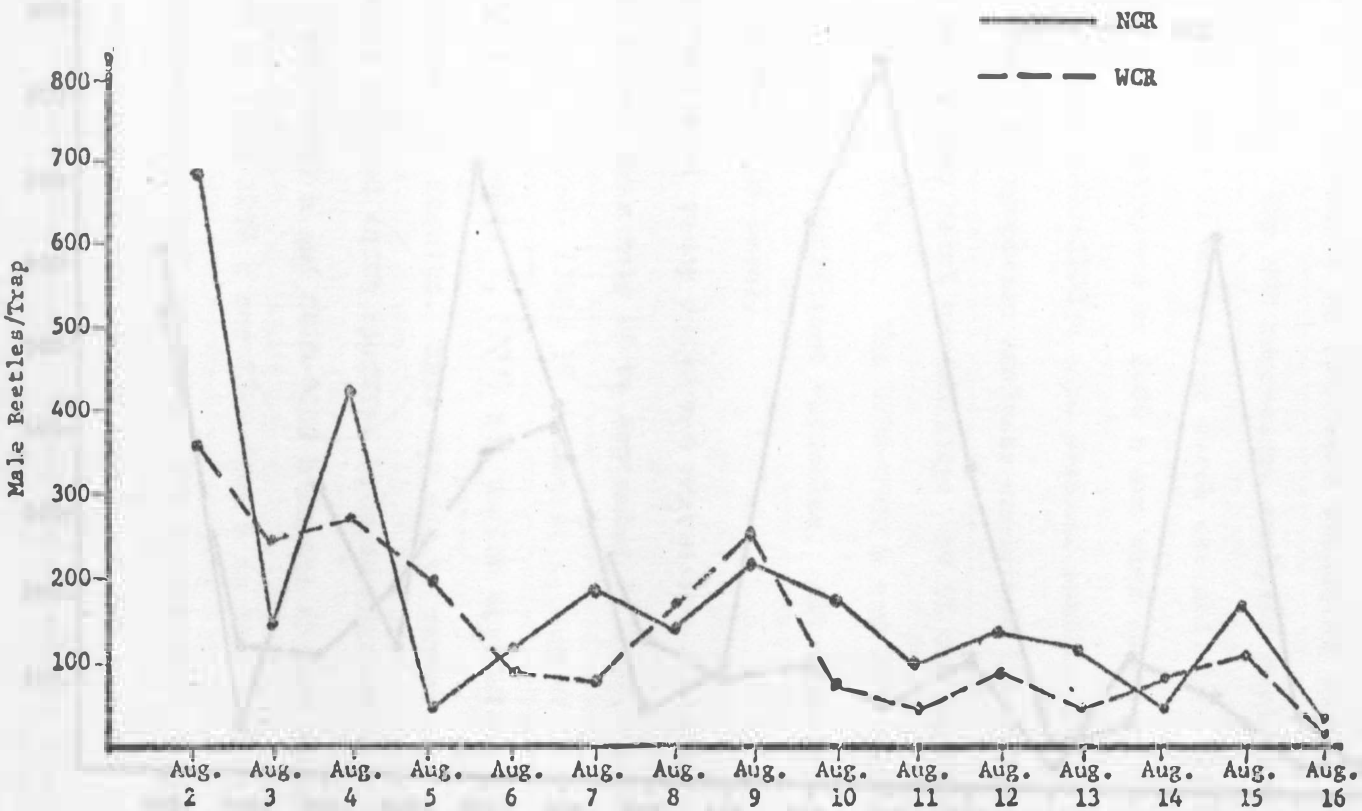

Fig. 4.-NCR and WCR males trapped in the field with 50 ul WCR pheromone concentration (Daily trap catch from Aug. 2 to Aug. 16 at 0830 CDT).

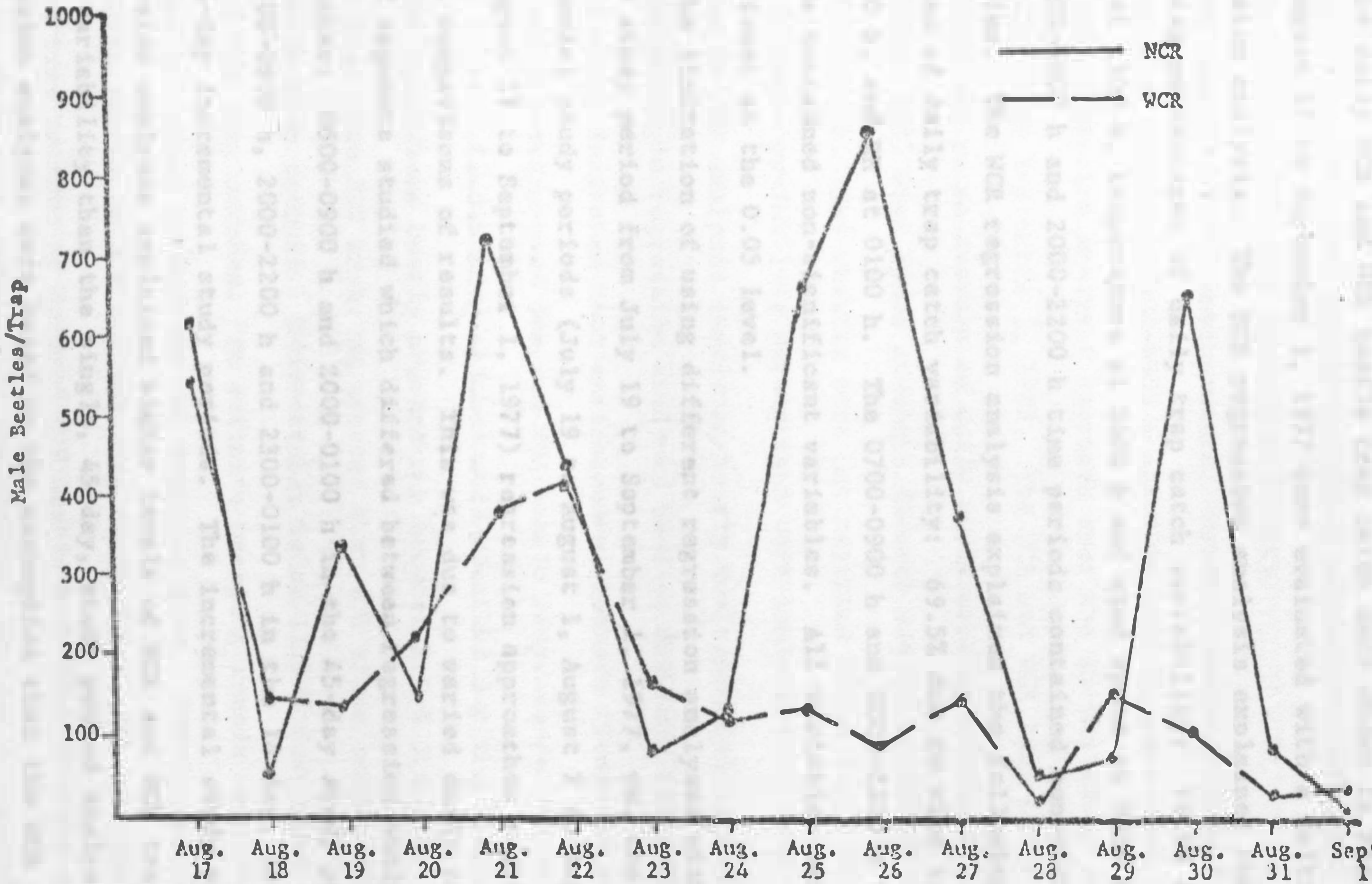

Fig. 5.-NCR and WCR males trapped in the field with 50 ul WCR pheromone concentration (Daily trap catch from Aug. 17 to Sept. 1 at 0830 CDT).

8. Northern and western corn rootworm regression analysis (August 17 to September 1, 1977)

The daily NCR and WCR beetle trap catch data shown in Fig. 5 from August 17 to September 1, 1977 were evaluated with a multiple regression analysis. The NCR regression analysis explained the following percentages of daily trap catch variability: 76.9% due to RH at 2300 h, temperature at 2400 h and wind speed at 0100 h. The 0700-0900 h and 2000-2200 h time periods contained non-significant variables. The WCR regression analysis explained the following percentages of daily trap catch variability: 69.5% due to wind speed at 2400 h, and RH at 0100 h. The 0700-0900 h and 2000-2200 h time periods contained non-significant variables. All variables were significant at the 0.05 level.

The limitation of using different regression analyses within the 45-day study period from July 19 to September 1, 1977, vs. the 3 separate incremental study periods (July 19 to August 1, August 2 to August 16, and August 17 to September 1, 1977) regression approaches restricts direct comparisons of results. This was due to varied daily time period segments studied which differed between regression analysis approaches: 0500-0900 h and 2000-0100 h in the 45-day study period vs. the 0700-0900 h, 2000-2200 h and 2300-0100 h in the 14-day, 15-day and 16-day incremental study periods. The incremental study period regression analyses explained higher levels of WCR and NCR trap catch variability than the single, 45-day, study period analysis. The regression analyses were based on the assumption that the WCR and NCR beetle daily response to the pheromone-baited traps were restricted to within each daily time period studied. The results indicated that changing CRW beetle population levels (B/P) and exposed pheromone variability present over the 45-day study period were dominant factors which influenced CRW trap catch variability.

The average of the environmental variable readings from 2 daily separate time periods (0500-0900 h and 2000-0100 h) were used in a different regression analysis approach over the 45-day study period from July 19 to September 1, 1977. The NCR and WCR trap catch data were regressed on an average of daily environmental variable readings: temperature (°C) wind speed averages (m/sec) and RH at 0500-0900 h and 2000-0100 h. The results were not reported since lower NCR and WCR trap catch variability percentages were explained in this analysis compared to the analysis involving hourly environmental variable readings.

The multiple regression analyses used on CRW trap catch data in this study indicated that environmental factors (Temperature, wind speed and RH) influenced NCR and WCR beetle response to pheromone-baited traps. Higher trap catches were obtained for the NCR and WCR when the wind speed hourly average was between 2.0-4.5 m/sec. Wind speeds less than 2.0 m/sec or greater than 4.5 m/sec caused reduced CRW beetle trap catches. Temperatures below 11.2°C decreased the NCR and WCR trap catches. No definite trapping trends were observed with tha RH effect on NCR and WCR trapping data. Precipitation was a limiting factor on NCR and WCR trap catch data. Dew on plants reduced trap catches or delayed CRW beetle activity to later in the morning. This data agreed with the results obtained by Bartelt and Chiang in 1977.

Bartelt and Chiang (1977) suggested that the remaining WCR and NCR trap catch variability may be accounted for by the competition from female beetles in the field and their effect on male beetle response toward a pheromone source. Comparison of virgin females with the WCR pheromone extract-baited traps was not attempted in this study.

D. Irrigated Field Effect on CRW Beetle Response to Pheromone-Baited Traps.

Field tests were conducted in 2 irrigated fields in Turner County during August, 1976. Three sticky traps were placed in each field on August 4. The traps were baited with a crude (1.5 ml), unfractionated WCR pheromone extract. The WCR and NCR beetles were collected daily from August 5 to August 13 in field A (Fig. 6) and field B (Fig. 7). Fields A and B had estimated CRW beetle populations (B/P basis) during the 9-day study period of 8 and 9 B/P respectively. The trap catch means from the unexposed pheromone traps are listed in Table 2 for fields A and B (Fig. 6 and 7). The WCR:NCR species ratio was ca. 50:50 in each field tested.

On both August 7 and August 12 the pivitol irrigation system passed over the traps at 1200 h. The passage of the irrigation system over the traps at 1200 h influenced trap catch less (Fig. 6) than when the system passed over the traps during early morning or late evening hours (Fig. 7) on August 7 at 0800 h and on August 11 at 2000 h. The pivitol irrigation system passed over trap A at 1800 h as compared to trap B at 2400 h and trap C at 0600 h on August 11 and 12. The trap catch obtained on trap A was almost 2 times that obtained on

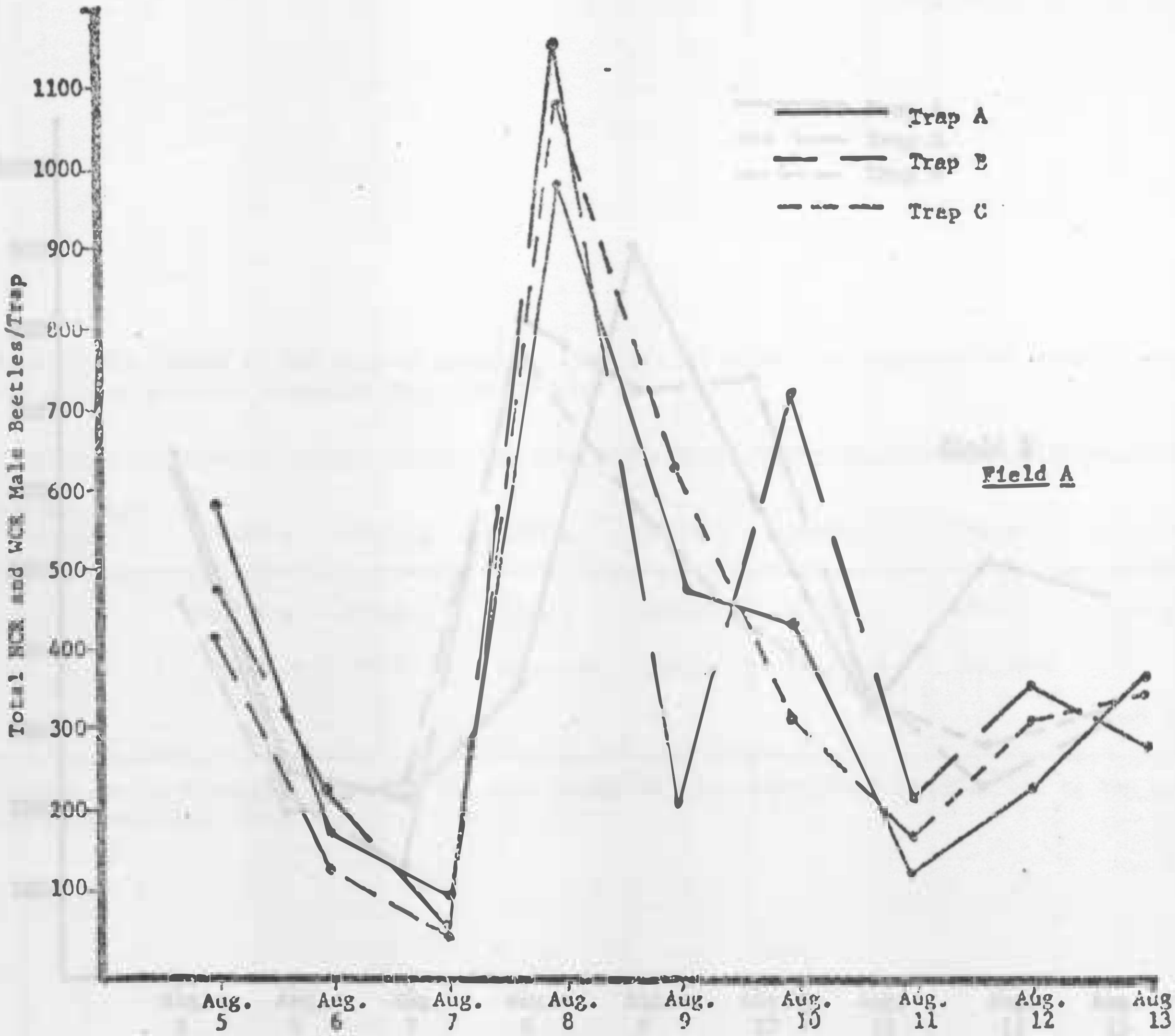

Fig. 6.-Total NCR and WCR males trapped in the field with an unfractionated (1.5 ml) WCR pheromone concentration - Field A (Daily trap catch at 1230 CDT).

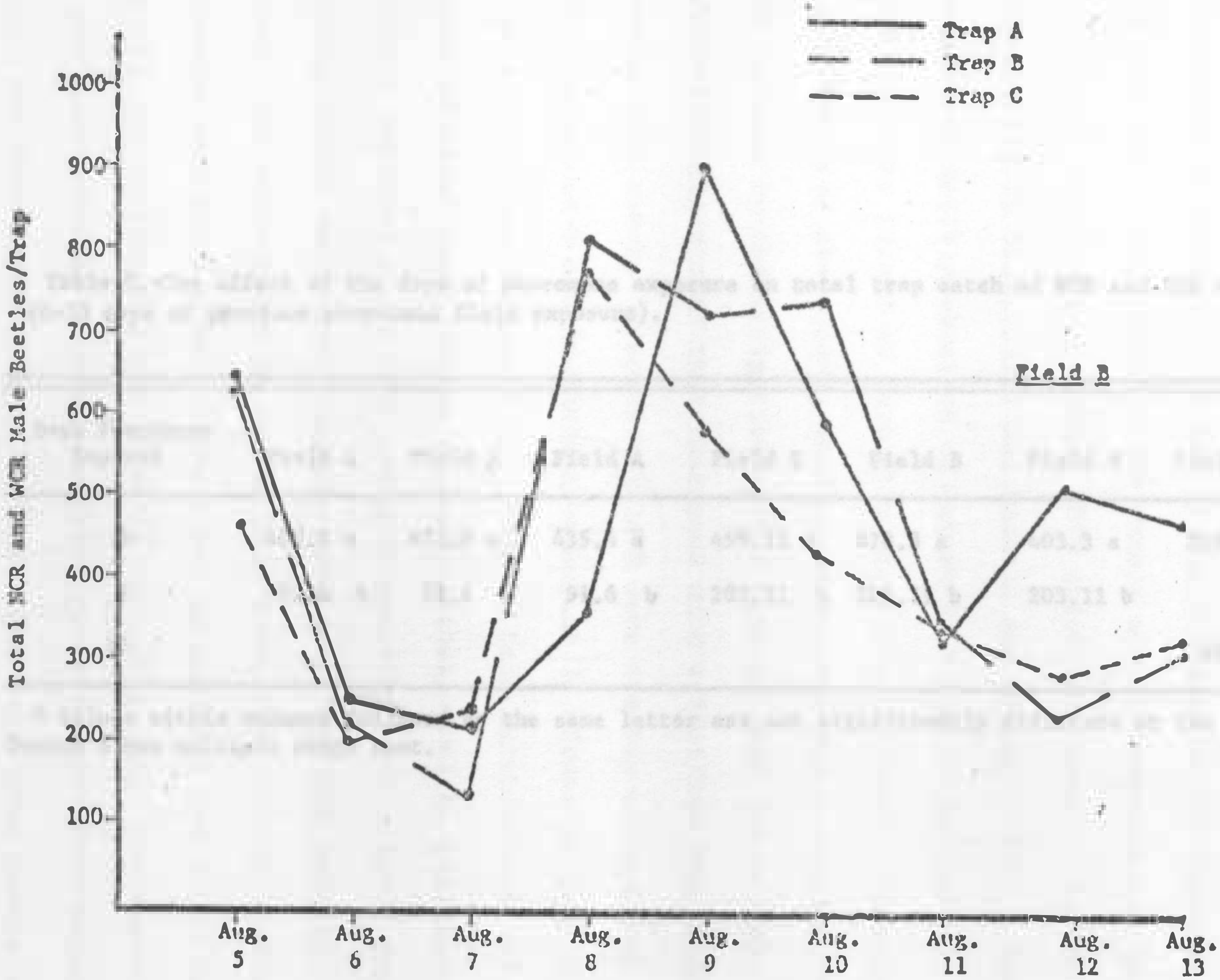

Fig. 7.-Total NCR and WCR males trapped in the field with an unfractionated (1.5 ml) WCR pheromone concentration - Field B (Daily trap catch at 1030 CDT).

Table 2.-The effect of the days of pheromone exposure on total trap catch of WCR and NCR male beetles. (0-10 days of previous pheromone field exposure).

Days Pheromone Exposed	Field A	Field A	Field A	Field B	Field B	Field B	Field C	Field D
0	400.4 a	411.8 a	435.4 a	459.11 a	478.3 a	403.3 a	210 a	357 a
9	91.6 b	91.6 b	91.6 b	203.11 b	203.11 b	203.11 b		
10							65 a	93.4 a

[a] Values within columns followed by the same letter are not significantly different at the 0.05 level by Duncan's new multiple range test.

either trap B or C. The response by the CRW beetles to trap A was less inhibited by the irrigation system during the early morning hours than traps B or C. This may have increased the trap catch on trap A in comparison to traps B and C, which were affected by the irrigation system during most of the early morning hours.

In fields A and B (Fig. 6 and 7) the decline in CRW trap catch on August 6 and 7 were probably the result of low temperatures during the collection periods approaching 10°C which was shown to reduce CRW beetle activity by Guss (1976) and Bartelt and Chiang (1977). The increased trap catches obtained on August 8, 9 and 10 in field B may have been the result of favorable weather conditions: temperature overnight remained above 18°C, wind speed was between 4-8 m/sec, and high RH (caused by the irrigation system passage over the traps). Bartelt and Chiang stated that increased wind velocities increased CRW beetle trap catch. Traps in field B were freshly-coated with adhesive on August 6 and in field A on August 7. Traps in both fields were not recoated until August 10. Reduced trap catches were obtained on August 11 which could not be related to environmental factors: temperature remained above 16°C and wind speed ca. 4-6 m/sec. Bartelt and Chiang (1977) determined that the catches of the CRW beetles increased with temperature up to ca. 26.5°C and with rising wind speed. The adhesive application to the traps was on August 7 and 10 in field A (Fig. 6) and on August 6 and 10 in field B (Fig. 7). The recoated traps may have retained a greater percentage of beetles than traps which had not been recoated for 3-5 days. The lower trap counts later in the study period indicated that fewer beetles were retained due to reduced adhesive on the traps.

The similar trap catch trends shown in Fig. 6 and 7 indicate consistency between trap catches on a daily basis in the same trap site area. The trap catches obtained from 1 trap appeared adequate for field population surveys of the CRW beetle. The trap catch data shown in Fig. 6 and 7 were relatively consistent on the same dates, taking in consideration the variable irrigation effects discussed previously.

A two-way analysis of variance was used to study the variability between daily trap catches (same dates) in fields A and B (Fig. 6 and 7). The daily CRW beetle trap catches were not significantly different at the .05 level on a day-to-day basis in either field A or B. The daily CRW beetle trap catches were significantly different at the .05 level between dates in both fields A and B (Fig. 6 and 7) by a two-way analysis of variance test. A SD analysis was conducted on traps A, B and C in field A (Fig. 6). This was done to obtain information on daily CRW trap catch variability and on the extent in which trap catches were predictable. Trap A had a mean of 435.4 and a SD of 375.67 from August 5-11. Trap B had a mean of 411.8 and a SD of 307.33 from August 5-11. Trap C had a mean of 400.4 and a SD of 351.3 from August 5-11. The estimated SD for each pheromone-baited trap was high, which suggests that daily CRW trap catch predictability would be difficult.

The daily CRW beetle trap catches from traps A, B and C in field B (Fig. 7) were regressed on temperature and wind speed obtained at a point 30 miles NE of the field studied. The daily trap catches were regressed on wind speed and temperature readings taken at 1800, 2100 and 2400 h. Trap B (field B, Fig. 7), trap catch data obtained significant results. Wind speed at 0600 h explained 54.2% of the daily CRW beetle trap catch variability. The environmental variables used in the 2 regression approaches were restricted by the 4 and 5 df in each analysis respectively.

E. Pheromone Field Exposure Range

The results obtained in this study determined that previous field exposure was an important factor influencing CRW beetle responsiveness. Field aging of the pheromone reduced attractiveness and the resulting trap catches. Guss (1976) indicated that a pheromone-baited trap remained attractive for at least 22 days. Attractiveness was compared to pheromone-baited trap catches and non-baited control trap-catch numbers. Bartelt and Chiang (1977) suggested that any pheromone baited trap catch greater than 3-SD above the non-baited control trap catch numbers should be considered attractive. The pheromone-baited trap catches obtained in this study would be considered attractive after at least 30 days (Table 3) based on previous work. No published information has shown the actual effect of declining concentration of pheromones with aging on CRW trap catch data. In this work first day effects of increased beetle response was noted.

Trapping data obtained in July, 1976, Turner County, indicated that pheromone preparations were less attractive to beetles within 9 days after their placement into the corn field. Field tests were conducted in August, 1976, to determine the influence of exposed pheromones on daily trap catch. Four fields (Table 2) were studied.

Fields A and B compared trap catch means between unexposed pheromone traps and a 9-day exposed pheromone trap. The 2 fields had average beetle per plant counts which were very similar over the trap collection period from August 5 to August 11. Field A had an estimated B/P count average of 8, while Field B had an estimated B/P count of 9. The CRW beetle species ratio averaged ca. 42% WCR and 58% NCR in Field A. Field B CRW beetle species ratio averaged ca. 52% WCR and 48% NCR. Tests in fields C and D compared trap catch means between an unexposed and 10-day exposed pheromone trap catch. The two fields had an estimated 2 and 3 B/P, respectively, over the 7 day-study period from August 10 to August 16. The CRW beetle species ratio was estimated to average ca. 20% NCR and 80% WCR in fields C and D, located in Brookings County.

Fields A and B, in Table 2, indicate that the response to the unexposed and 9-day exposed pheromone-baited sticky traps were statistically different as evaluated by Duncan's new-multiple range test. The unexposed pheromone consistently caught ca. 2-5 times the number of beetles collected on the 9-day exposed pheromone.

Trapping data obtained in fields C and D showed somewhat contrasting results. The trap catch means were not determined to be significantly different with a two-way analysis of variance or with Duncan's new-multiple range test. Even though the unexposed pheromone trap caught ca. 3-4 times the beetles collected on the 10-day exposed pheromone trap.

Exposed pheromone studies also were conducted in 1977, from August 2 until September 2, in Brookings County. The three corn fields studied had similar NCR beetle field populations estimated at 3 beetles per plant (50-total corn plant averages). The WCR beetle field population was less than 5% of the total natural population in the corn fields studied. All ice cream carton traps were placed at ear tip height between 18 and 36 m from the corn field border.

Eight separate exposed pheromone tests were analyzed statistically with a two-way analysis of variance and with Duncan's new-multiple range test (Table 3). Six tests were evaluated in Field A (A_1-A_6) from August 2 to August 15. One test was evaluated in Field B and Field C from August 26 and 27 to September 2, respectively.

In test A_1 (Table 3), 3 exposed pheromones were studied (Fig. 8). The trend continued with reduced beetle response to older pheromones as opposed to fresher pheromones. A similar trend was demonstrated by the remainder of the tests summarized in Table 3. Tests A_1, A_2, A_3, A_5 and C are significant at the .01 level. Tests A_4 and A_6 are significant at the .05 level.

Tests A_1, A_4 and A_5 show that exposed pheromones 27 to 30 days old are still attractive. For these pheromone-baited sticky traps attracted more beetles than the control traps at probability levels of .01.

Tests A_6, B and C illustrate the trap catch mean differences between an unexposed pheromone consistently attracted greater numbers of beetles than the 17-day exposed pheromone (Fig. 9 and 10). Significant daily trap catch variation occurred over the study period. The variability in trap catches (Fig. 9 and 10) are similar between fields B and C.

Table 3.-The effect of days of pheromone exposure on NCR male beetle trap catch (0-30 days of previous pheromone field exposure).[a]

Days Pheromone Exposed	Field A_1	Field A_2	Field A_3	Field A_4	Field A_5	Field A_6	Field B	Field C
0-Day Exposure						583.4 a	452.4 a	705.4 a
9-Day Exposure	438.3 a	678.2 a	716.4 a					
15-Day Exposure	274.0 b	414.7 b						
17-Day Exposure			340.6 b	294.4 a		340.6 b	49.9 a	118.0 b
27-Day Exposure	146.0 c			186.4 b				
30-Day Exposure					125.7 a			
Control	51.4 d			80.9 c	51.4 b			

[a] Values within columns followed by the same letter are not significantly different at the 0.05 level by Duncan's new-multiple range test.

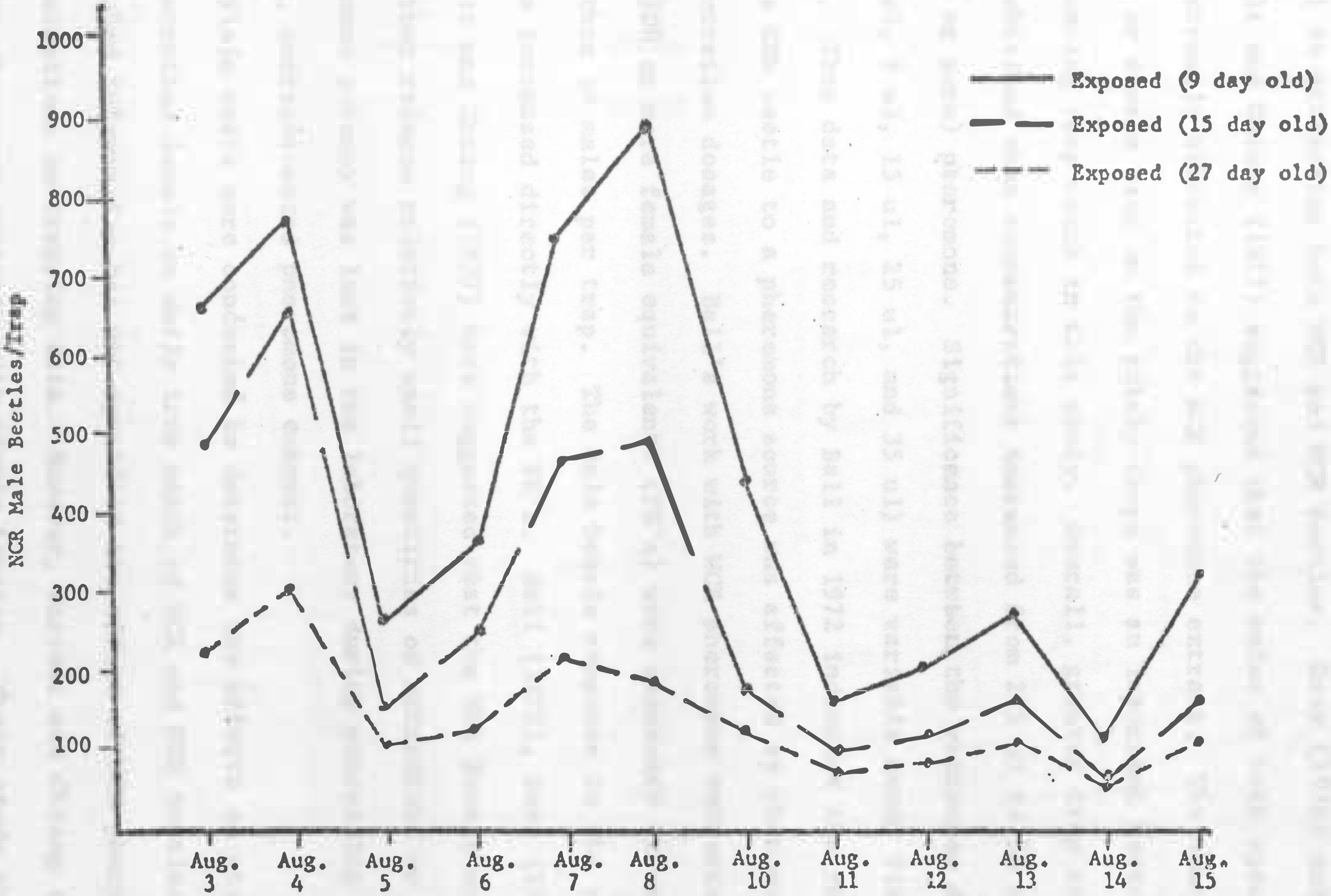

Fig. 8.-NCR males trapped in the field with exposed 50 ul WCR pheromones - Exposed 9-27 days (Daily trap catch at 0930 CDT).

F. Pheromone Concentration (2.5 ul to 50 ul)

The WCR sex-attractant pheromone was shown in this research to be useful in attracting both NCR and WCR beetles. Guss (1976) and Bartelt and Chiang (1977) suggested that the males of both species were strongly attracted to the WCR pheromone extract. The concentration level or dosage used on the sticky traps was an important factor influencing trap catch in this study. Overall, greater trap catches were obtained when concentrations increased from 2.5 ul to 50 ul/ml (1-20 ng pure) pheromone. Significance between the pheromone dilutions (2.5 ul, 5 ul, 15 ul, 25 ul, and 35 ul) were variable among field tests. This data and research by Ball in 1972 indicated the response by the CRW beetle to a pheromone source was affected by pheromone concentration dosages. Ball's work with WCR pheromone extracts showed that 500 or more female equivalents (FE's) were necessary to attract more than 10 males per trap. The male beetle response to the pheromone source increased directly with the FE's. Ball (1972), Guss (1976) and Bartelt and Chiang (1977) have suggested that the WCR female appears to either release relatively small quantities of attractant or that pheromone potency was lost in the laboratory during processing of the crude, unfractionated pheromone extract.

Field tests were conducted to determine the effects of pheromone concentration levels on daily trap catch of WCR and NCR beetles. Published information has not specified the effect of WCR pheromone concentrations on trapping data. However, Bartelt and Chiang (1977) did compare pheromone extracts with virgin females. Their study showed that males of both species were strongly attracted to virgin females of

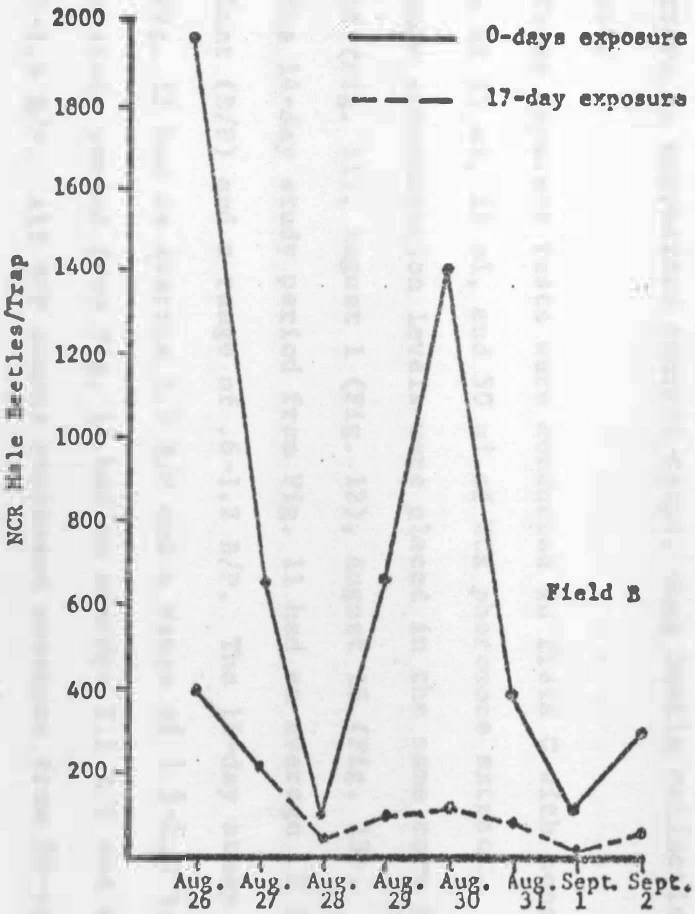

Fig. 9-NCR males trapped in the field with exposed 50 ul WCR pheromones - Field B (Daily trap catch at 0100 CDT).

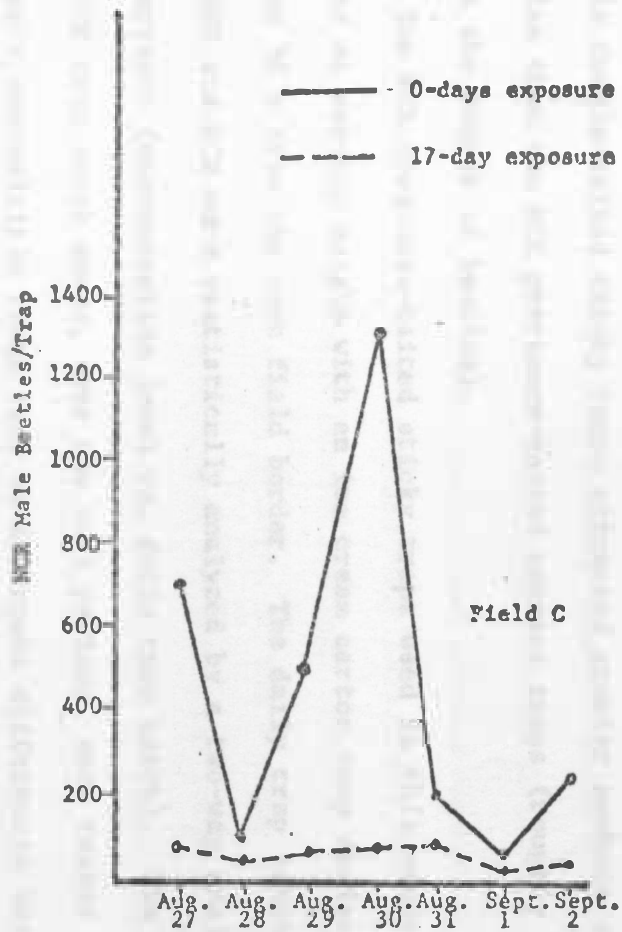

Fig. 10.-NCR males trapped in the field with exposed 50 ul WCR pheromones - Field C (Daily trap catch at 0200 CDT).

either species, as well as to the WCR pheromone extract. One virgin female/trap attracted similar numbers of WCR and NCR beetles. The virgin female-baited sticky traps attracted greater numbers of WCR beetles than the WCR pheromone-baited extract traps (roughly 1.35 times the number of beetles).

The WCR pheromone-baited sticky traps used in this study were placed at ear-tip height with an ice cream carton trap design between 18 and 36 m from the corn field border. The daily trap catches for the NCR and WCR were statistically analyzed by a two-way analysis of variance (concentration level vs. daily trap catch). The NCR and WCR trap catch means, over the test periods, were ranked with Duncan's new-multiple range test to interpret differences between trap catch means. Generally, pheromone traps were 10-15 times as attractive as non-baited control traps, when beetle collections were compared.

Three separate tests were conducted in field C with concentration levels of 15 ul, 35 ul, and 50 ul of WCR pheromone extract. The 3 pheromone concentration levels were placed in the same corn field on July 18 (Fig. 11), August 1 (Fig. 12), August 16 (Fig. 13).

The 14-day study period from Fig. 11 had an average .7 beetles per plant (B/P) and a range of .6-1.2 B/P. The 15-day study period from Fig. 12 had an average 1.5 B/P and a range of 1.2-2.0 B/P. The 16-day study period from Fig. 13 had an average 2.2 B/P and a range of 2.0-2.5 B/P. All B/P counts represent averages from 50-total corn plant counts, randomly selected from the study area.

Fig. 11, 12, and 13 show a first day trap catch phenomena after the placement of a fresh pheromone into the corn field. The first day trap catch was consistently greater than all other daily trap catches in the study period. Significant trap catch variations occurred between August 1 and August 2 and between August 16 and August 17. The 3 figures also graphically illustrate the effect of increasing the WCR pheromone extract per trap from 15 ul to 50 ul. Greater daily trap catches were obtained in the 3 study periods presumably because the WCR pheromone concentration level was increased.

Significant differences in trap catch were obtained between Fig. 11, 12 and 13 as the B/P average increased from .7 B/P in Fig. 11 to 1.5 B/P in Fig. 12 to 2.2 B/P in Fig. 13. The variability among days also was greater as the B/P average increased in the 3 figures.

CRW trap catch data shown in Fig. 12 and 13 were significant by a two-way analysis of variance test. A Duncan's new-multiple range test was used to determine significant trap catch mean differences. Results indicated the trap catch mean for the 50 ul trap was significantly greater than either the 35 ul or 15 ul trap catch means. Trapping data from the 35 ul and 15 ul traps in Fig. 12 were questionable. Negative results were obtained as the 15 ul trap catch mean was significantly larger than the 35 ul trap catch mean. Distance from the corn field border may have influenced this comparison. The 50 ul and 15 ul traps were 36 m from the corn field border. The 35 ul trap was 15 m from the corn field border. The B/P counts obtained in 1976, from a corn field in Turner County, showed that the B/P count averages decreased from 13-15 B/P, 75 m from the corn field border to 6-7 B/P, 25 m from the corn field border.

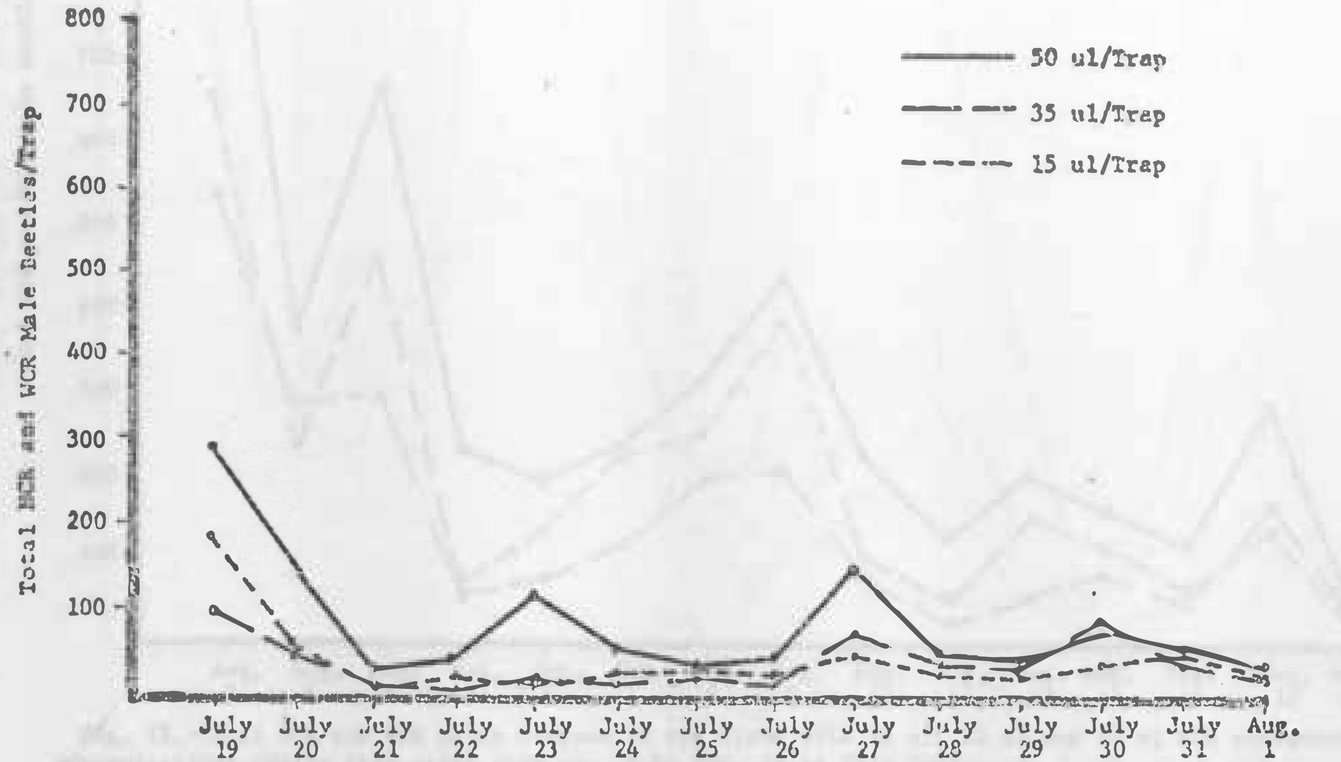

Fig. 11.-Total NCR and WCR males trapped in the field with 15 ul, 35 ul and 50 ul WCR pheromone concentrations (Daily trap catch from July 19 to Aug. 1 at 0830 CDT).

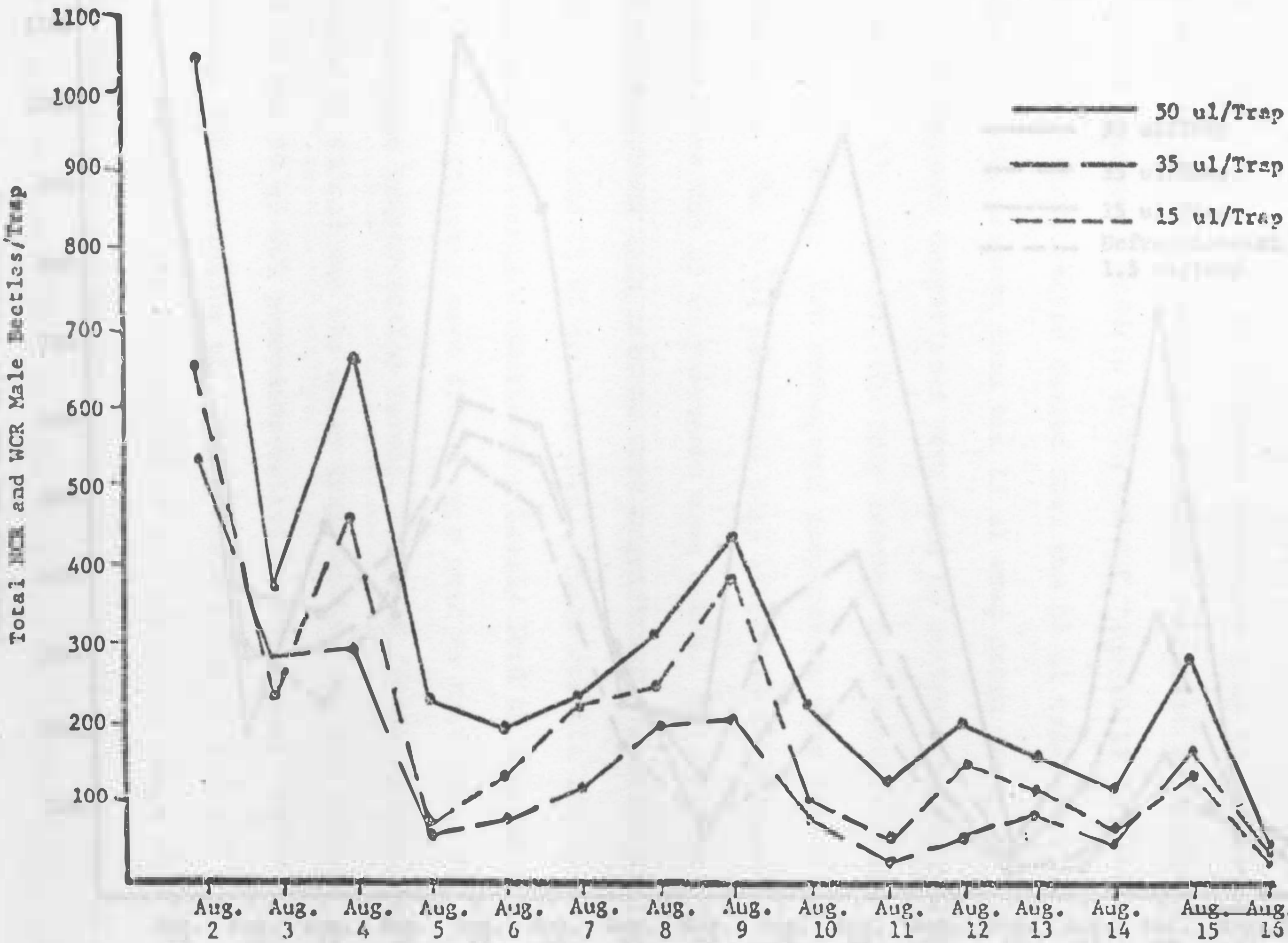

Fig. 12.-Total NCR and WCR males trapped in the field with 15 ul, 35 ul and 50 ul WCR pheromone concentrations (Daily trap catch from Aug. 2 to Aug. 16 at 0830 CDT).

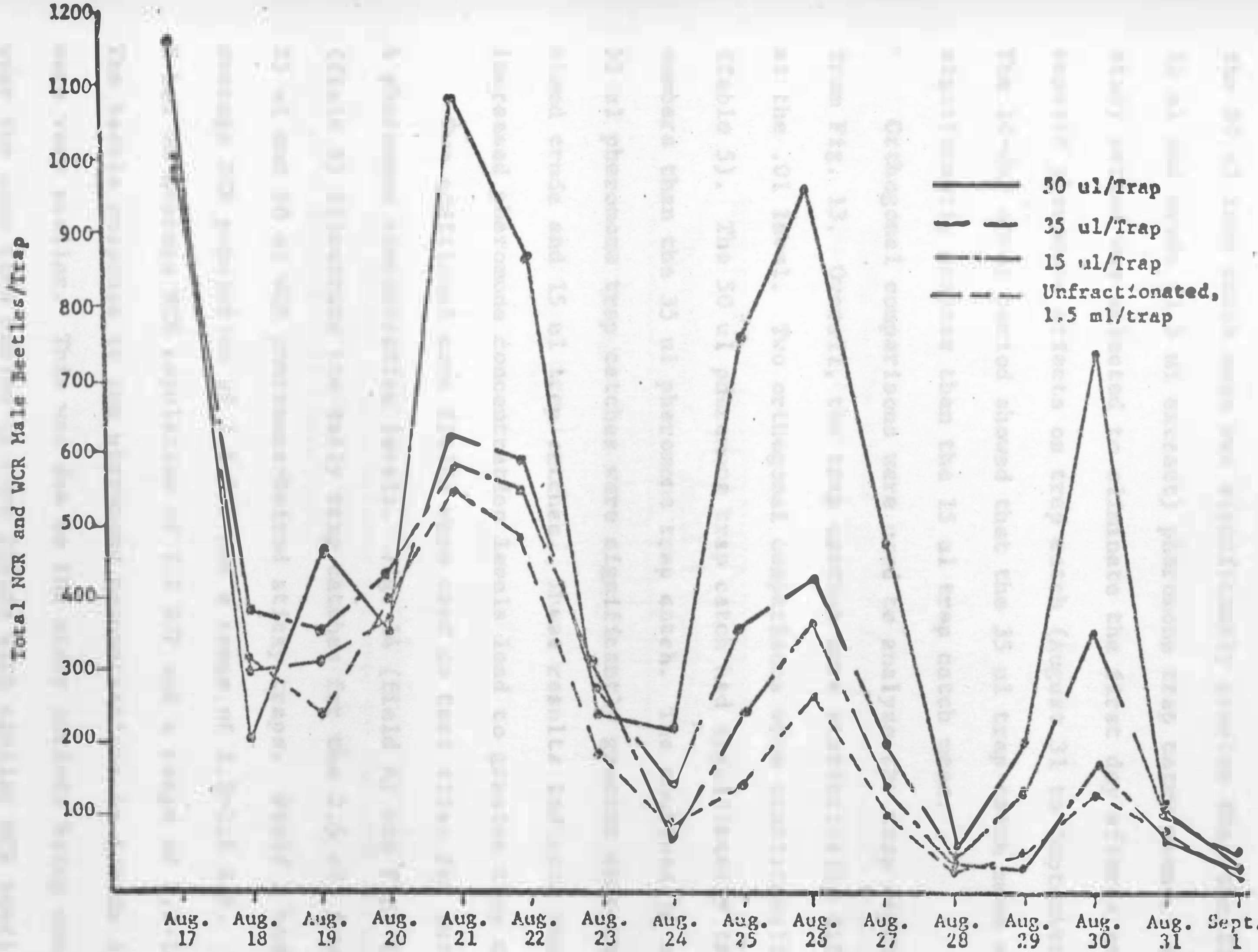

Fig. 13.-Total NCR and WCR males trapped in the field with unfractionated, 15 ul, 35 ul and 50 ul WCR pheromone concentrations (Daily trap catch from Aug. 17 to Sept. 1 at 0830 CDT).

The trap catch data from Fig. 13 was analyzed by Duncan's new-multiple range test (Table 4). This 16-day study period showed that the 50 ul trap catch mean was significantly greater than the 35 ul, 15 ul and crude (1.5 ml extract) pheromone trap catch means. A 10-day study period was selected to eliminate the first day effects and the exposed pheromone effects on trap catch (August 31 to September 2). The 10-day study period showed that the 35 ul trap catch mean was significantly greater than the 15 ul trap catch mean.

Orthogonal comparisons were used to analyze the trap catch data from Fig. 13. Overall, the trap catches were statistically different at the .01 level. Two orthogonal comparisons were statistically different (Table 5). The 50 ul pheromone trap catch had significantly larger numbers than the 35 ul pheromone trap catch. The combined 50 ul and 35 ul pheromone trap catches were significantly greater than the combined crude and 15 ul trap catches. These results indicate that increased pheromone concentration levels lead to greater trap catch.

Two additional corn fields were used as test sites for introducing 4 pheromone concentration levels. Fig. 14 (field A) and Fig. 15 (field B) illustrate the daily trap catches for the 2.5 ul, 5 ul, 25 ul and 50 ul WCR pheromone-baited sticky traps. Field A had an average NCR population of 1.8 B/P and a range of 1.2-2.0 B/P. Field B had an average NCR population of 1.2 B/P and a range of 1.0-1.4 B/P. The beetle response to the pheromone concentrations in fields A and B were very similar. This was due to the study periods being conducted over the same time period in corn fields with similar NCR beetle populations.

Table 4.-The effect of WCR pheromone concentration on total trap catch of NCR and WCR male beetles (Field C).[a]

Concentration	Field C (16 Dates)	Field C (10 Dates)
15 ul	255.25 a	209.90 a
Unfractionated (1.5 ml)	309.94 a	261.11 ab
35 ul	331.56 a	320.60 b
50 ul	489.20 b	582.90 c

[a] Values within columns followed by the same letter are not significantly different at the 0.05 level by Duncan's new-multiple range test.

Table 5.-The effect of WCR pheromone concentrations on total trap catch of WCR and NCR beetles - Orthogonal comparisons.

Orthogonal Comparisons:

Treatment	50 ul	35 ul	Crude	15 ul			
Treatment Total	7927	5305	4959	4084	Q	Kr	SS
Comparison							
50 ul vs. 35 ul	+1	-1	0	0	2622	2 (16)	214840.12
Crude vs. 15 ul	0	0	+1	-1	875	2 (16)	23925.78
50 ul, 35 ul vs. Crude, 15 ul	+1	+1	-1	-1	4189	4 (16)	274183.14
TOTAL							512949.04

Analysis of Variance:

Source	df	SS	MS	F
Blocks	15	4540244.00	302682.88	
Comparison 1, 2 and 3	3	1538847.00	512949.00	35.78*
50 ul vs. 35 ul	1	214840.12	214840.12	14.99*
Crude vs. 15 ul	1	23925.78	23925.78	1.67
Comparison 1 vs. Comparison 2	1	274183.14	274183.14	19.13*
Error	45	645116.00	14335.91	
TOTAL	63	5698309.00		

* Significant at the 1% level of significance.

F = 8.77

The trap catch means from fields A and B (Fig. 14 and 15) were analyzed by a Duncan's new-multiple range test (Table 6). Field A differs from field B only between the 5 ul and 25 ul pheromone trap catch means. The 5 ul and 25 ul trap catch means were significantly different in field B and were not significantly different in field A. This analysis points out the occurance of some inconsistency in trap catch means obtained on a field-to-field basis. The overall trend indicated consistently greater NCR trap catches obtained with the pheromone concentration increased from 2.5 ul to 50 ul pheromone per trap.

Orthogonal comparisons were used to analyze the trap catch data from Fig. 14 (field A) and Fig. 15 (field B). The trap catches were significantly different within each field at the .01 level by a two-way analysis of variance. Similar results were obtained in Tables 7 and 8 from the trap catch data in Fig. 14 and 15, respectively. In both Tables 7 and 8 only one orthogonal comparison was statistically different. The combined 2.5 ul and 5 ul pheromone trap catches were significantly different than the combined 25 ul and 50 ul pheromone trap catches. The results also indicated that increased pheromone concentration levels lead to greater trap catch.

The effect of pheromone concentration level on NCR beetle response is summarized in Table 9. Duncan's new-multiple range test was used to evaluate trap catch mean differences obtained in 6 corn fields between 25 ul and 50 ul pheromone-baited sticky trap catches. The beetle per plant (B/P) averages for the 6 fields are as follows: field A, 1.8 B/P; field B, 1.2 B/P; field C, .9 B/P; field D, .7 B/P;

Table 6.-The effect of WCR pheromone concentration on NCR male beetle trap catch (Fields A and B).[a]

Concentration	Field A	Field B
2.5 ul	119.22 a	94.22 a
5 ul	277.66 ab	121.44 a
25 ul	531.88 bc	463.88 b
50 ul	730.44 c	611.11 b

[a] Values within columns followed by the same letter are not significantly different at the 0.05 level by Duncan's new-multiple range test.

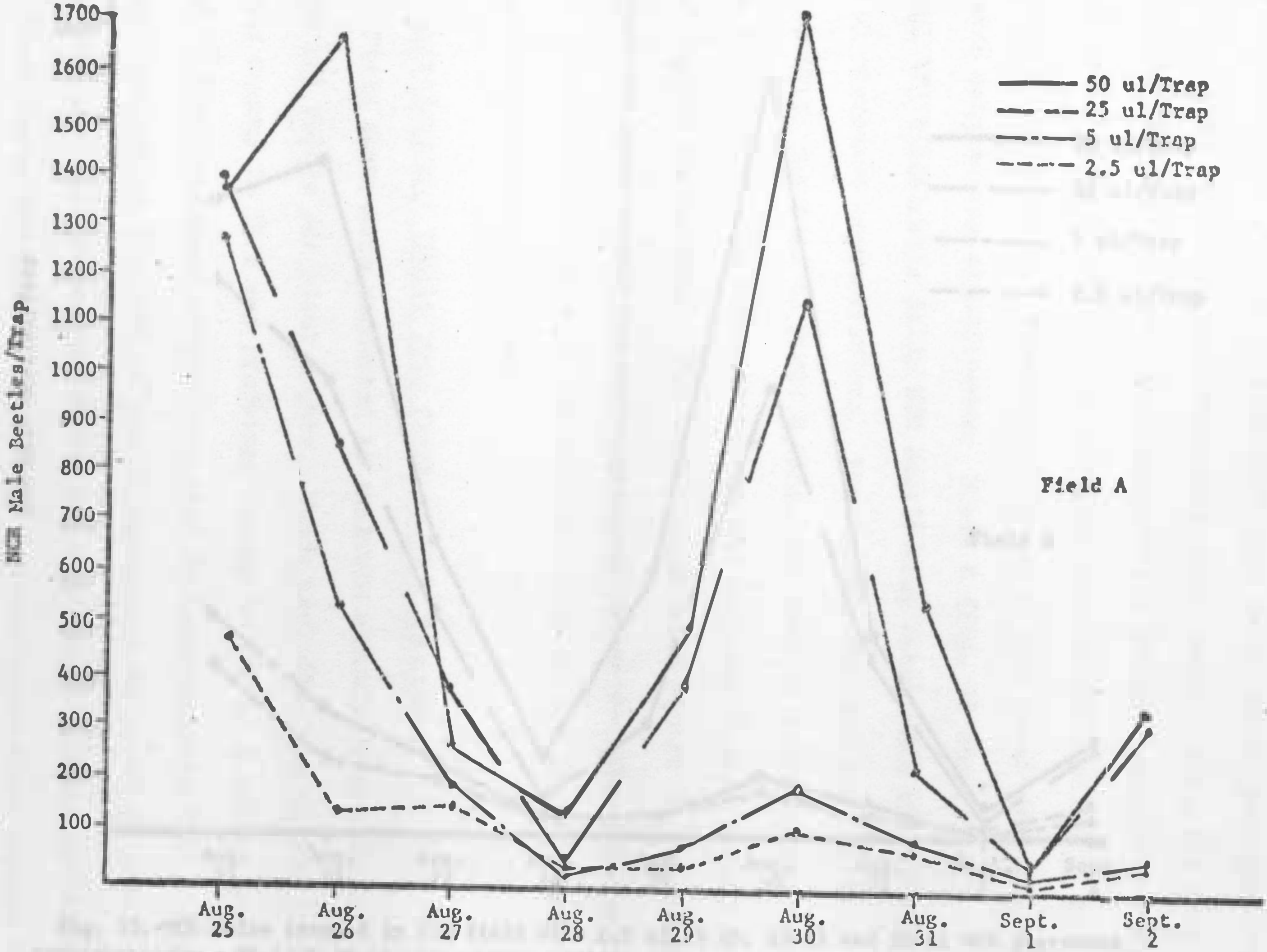

Fig. 14.-NCR males trapped in the field with 2.5 ul, 25 ul and 50 ul WCR pheromone concentrations - Field A (Daily trap catch at 1030 CDT).

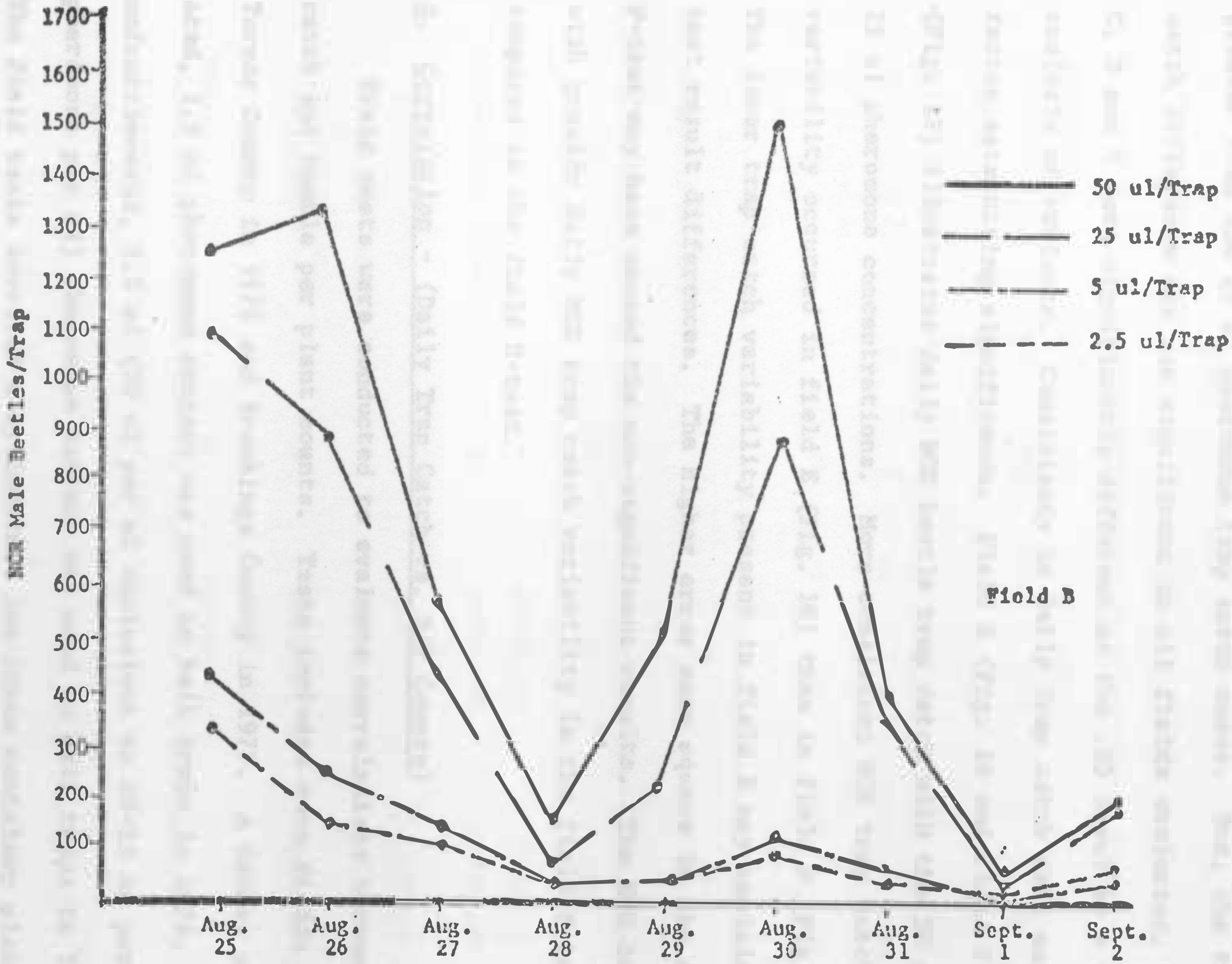

Fig. 15.-NCR males trapped in the field with 2.5 ul, 5 ul, 25 ul and 50 ul WCR pheromone concentrations - Field B (Daily trap catch at 1130 CDT).

field E, .7 B/P; and field F, 3.0 B/P. The variable results obtained indicate some inconsistency between trap catch differences on a field-to-field basis. The 50 ul pheromone trap catch means were consistently greater than the 25 ul pheromone trap catch means. But, the trap catch difference was not significant in all fields evaluated. Fields C, D and E were significantly different at the .05 level by a two-way analysis of variance. Consistency in daily trap catch data may be a factor determining significance. Field E (Fig. 16 and field F (Fig. 17) illustrates daily NCR beetle trap catch with the 50 ul and 25 ul pheromone concentrations. More consistent NCR trap catch variability occurred in field E (Fig. 16) than in field F (Fig. 17). The lower trap catch variability present in field E may explain the test result differences. The higher error mean square in the field F-test may have caused the non-significant results. The EMS increased with greater daily NCR trap catch variability in the field F-test as compared to the field E-test.

G. Correlation - (Daily Trap Catch vs. B/P Counts)

Field tests were conducted to evaluate correlations between trap catch and beetle per plant counts. Tests included corn fields from Turner County in 1976 and Brookings County in 1977. A crude, unfractionated, 1.5 ml pheromone extract was used to bait traps in 1976. A crude, unfractionated, 1.0 ml (50 ul per ml equivalent to 20-25 ng pure pheromone per ml) pheromone extract was used to bait traps in 1977. The field tests involved a cylindrical ice cream container placed at canopy height in 1976 and at ear-tip height in 1977. The entire exterior

Table 7.-The effect of WCR pheromone concentrations on total trap catch of WCR beetles - Orthogonal comparisons.

Orthogonal Comparisons:

Treatment	2.5 ul	5 ul	25 ul	50 ul			
Treatment Total	1073	2499	4787	6574	Q	Kr	SS
Comparison							
2.5 ul vs. 5 ul	+1	-1	0	0	-1426	2 (9)	112970.88
25 ul vs. 50 ul	0	0	+1	-1	-1787	2 (9)	177409.38
2.5 ul, 5 ul vs. 25 ul, 50 ul	+1	+1	-1	-1	-7789	4 (9)	1685236.60
TOTAL							1975616.8

Analysis of Variance:

Source	df	SS	MS	F
Blocks	8	4809201.00	601150.13	
Comparison 1, 2 and 3	3	5926845.00	1975615.00	23.17*
2.5 ul vs. 5 ul	1	112970.88	112970.88	1.33
25 ul vs. 50 ul	1	177409.38	177409.38	2.08
Comparison 1 vs. Comparison 2	1	1685236.60	1685236.60	19.76*
Error	24	2046362.00	85265.06	
TOTAL	35	8831178.00		

* Significant at the 1% level of significance.

F = 9.55

Table 8.-The effect of WCR pherowone concentrations on total trap catch of NCR beetles - Orthogonal comparisons.

Orthogonal Comparisons:

Treatment	2.5 ul	5 ul	25 ul	50 ul			
Treatment Total	848	1093	4175	5950	Q	Kr	SS
Comparison							
2.5 ul vs. 5 ul	+1	-1	0	0	-235	2 (9)	3334.72
25 ul vs 50 ul	0	0	+1	-1	-1775	2 (9)	175034.72
2.5 ul, 5 ul vs. 25 ul, 50 ul	+1	+1	-1	-1	-8184	4 (9)	1860496.00
TOTAL							2038865.4

Analysis of Variance:

Source	df	SS	MS	F
Blocks	8	2598340.00	324792.00	
Comparison 1, 2 and 3	3	6116595.00	2038865.00	37.46*
2.5 ul vs. 5 ul	1	3334.72	3334.72	0.06
25 ul vs. 50 ul	1	175034.72	175034.72	3.22
Comparison 1 vs. Comparison 2	1	1860496.00	1860496.00	34.18*
Error	24	1306271.00	54427.96	
TOTAL	35	5943476.00		

* Significant at the 1% level of significance.

F = 9.55

Table 9.-The effect of WCR pheromone concentration on NCR male beetle trap catch (Fields A-F).[a]

Concentration	Field A	Field B	Field C	Field D	Field E	Field F
50 ul	730.4 a	661.1 a	394.0 a	244.0 a	276.1 a	1225.0 a
25 ul	531.9 a	463.9 a	278.0 b	153.0 b	195.7 b	974.0 a

[a] Values within columns followed by the same letter are not significantly different at the 0.05 level by Duncan's new-multiple range test.

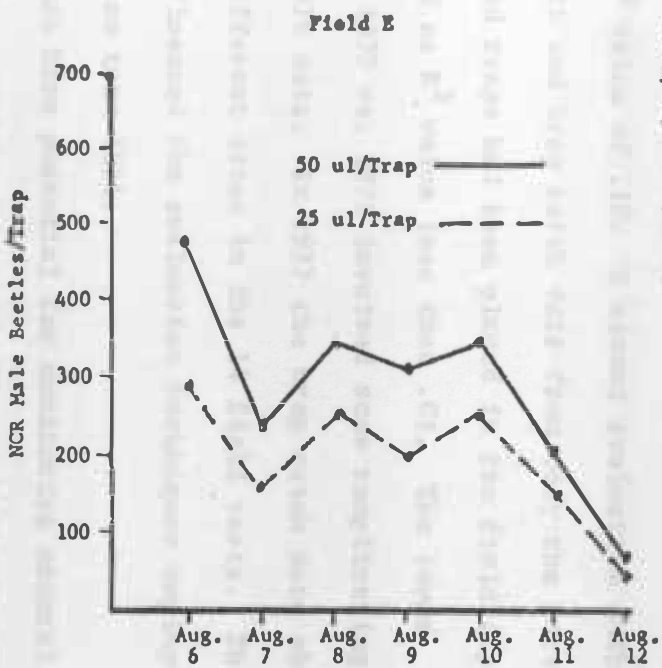

Fig. 16.-NCR males trapped in the field with 25 ul and 50 ul pheromone concentrations - Field E (Daily trap catch at 1130 CDT).

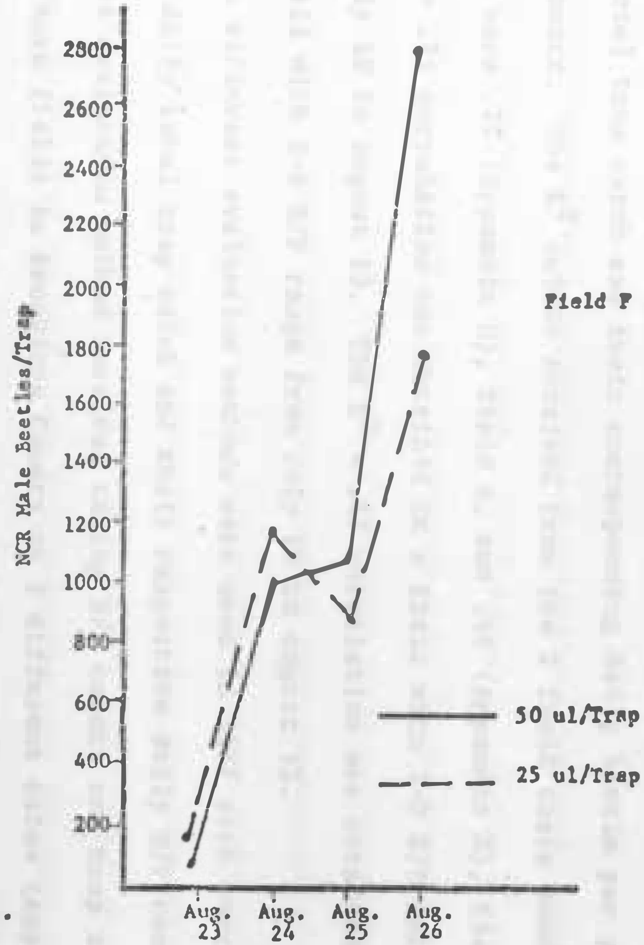

Fig. 17.-NCR males trapped in the field with 25 ul and 50 ul WCR pheromone concentrations - Field F (Daily trap catch at 0200 CDT).

portion of the trap and stake were coated with the Stikem Special®. Traps were placed 60 m from the field border in 1976 and 18-36 m in 1977.

The evaluation method used in 1976 involved correlations between daily total trap catch and their corresponding daily beetle per plant (B/P) counts. The R^2 values obtained from the 2 field tests conducted in 1976 were .29 (Appendix D), field A, and .48 (Appendix E), field B. The R^2 = .29 correlation was obtained in a field with 1-8 B/P range from July 10 to August 13. The R^2 = .47 correlation was obtained in a field with 3-9 B/P range from July 10 to August 13.

Two different evaluation methods were used in 1977 with correlations between daily total trap catch and their respective daily B/P counts. The first evaluation method involved taking B/P counts and trap catches from 14 corn fields in Brookings County on 3 different dates (Appendix F). This method obtained a R^2 value of .10. A second evaluation method involved taking B/P counts and trap catch data from only the first day after the pheromone-baited traps had been placed in the field (Appendix G). This method obtained an R^2 value less than .01. The lower correlations obtained in 1977 vs. 1976 involved some complicating factors not present in 1976 data. In 1977 the trap catch data obtained among fields were from different dates in the 14 field tests. Thus environmental factors influenced the evaluation techniques employed in 1977 to a greater degree than 1976.

The evaluation methods have potential for monitoring naturally infested CRW beetle field populations on a B/P basis, based on trap catch data obtained in 1976. The evaluation methods conducted in 1977 would have increased precision in predicting field populations on a B/P basis if the trap catch and B/P counts were taken among fields on the same respective dates. The 50-total plant count averages did appear adequate as a field population sampling technique in this study.

In 1977, correlations between pheromone-baited traps and non-baited control traps were obtained. An R^2 value of .87 was obtained from August 17 to August 28 in a field with 2-3 B/P (Appendix H). Average trap catches from pheromone traps were 10-15 times greater than the control traps. This study suggested that non-baited control traps have potential for predicting pheromone-baited trap catches. The non-baited control traps represented the random movement activity of the corn rootworm beetles. The R^2 values obtained between pheromone-baited and non-baited control traps indicated not only the high degree of pheromone trap catch predictability, but also the potential of the non-baited control traps for monitoring field populations.

VI. SUMMARY AND CONCLUSIONS

Two trap designs (ice cream carton and Pherocon II trap) and 2 trap heights (canopy and ear-tip height) were statistically analyzed with a two-way analysis of variance and Duncan's new-multiple range test. No significant differences between trap catch means were found with either trap height or trap design. Trap height was not significant at either tassel or ear-tip levels although ca. 2-3 times more beetles were captured at ear-tip height.

Multiple regression approaches were used to determine environmental factors affecting daily NCR and WCR trap catch variability: hourly variable readings of temperature (°C) wind speed average (m/sec) and RH. An R^2 value of 58.9% for the daily WCR trap catch variability was explained by these 3 environmental factors, previously mentioned. A strong relationship was shown between daily WCR trap catch and the 3 environmental factors studied in this analysis. The unexplained trap catch variability may have been due to changing beetle populations from .7 B/P on July 19 to 2.5 B/P on September 1, 1977. Also, field aging of the pheromone reduced attractiveness and the resulting trap catch.

Three separate incremental study periods (July 19 to August 1, August 2 to August 16 and August 17 to September 1, 1977) multiple regression analyses were conducted and provided higher R^2 values for NCR and WCR daily trap catch variability. Temperature (°C), wind speed average (m/sec) and RH explained 70-88% of the WCR beetle trap catch variability. Factors affecting the NCR in the three incremental periods showed that 40-82% of the NCR beetle trap catch variability was due to temperature (°C), wind speed average (m/sec) and RH.

Field tests conducted in 1976 and 1977 indicated that longer periods of previous field pheromone exposure lowered CRW beetle trap catches. This would be important from a correlation of environmental factors in previous studies and from a monitoring standpoint.

The effect of WCR pheromone concentration on trap catch data indicated a positive influence on beetle response to higher pheromone concentration dosages. The trap catch data also indicated that the greatest beetle response occurred the first day after the placement of a fresh pheromone-baited trap into a corn field (within environmental factor limitations). Orthogonal and Duncan's new-multiple range test indicated that as concentration dosages increased from 2.5 ul to 50 ul/trap the respective CRW trap counts increased significantly.

Correlations were found between daily CRW trap catch data and beetle per plant counts (B/P). Variable results were obtained between 1976 and 1977 depending on the evaluation method: 1976, R^2 = .29 and .48; 1977, R^2 = .01 and .10. The higher correlation obtained in 1976 indicated that trap catch variability within one corn field could be explained better than the trap catch variability between corn fields in the 1977 evaluation methods. The correlations obtained in 1976 indicate potential in monitoring CRW beetle field populations on a B/P basis with pheromone-baited sticky traps.

Correlations of .69 and .87 in 1977 were obtained between pheromone-baited traps and non-baited control traps suggested that control trap data could be a good indicator of beetle activity and beetle response to pheromone-baited traps.

Field tests conducted in 1976 and 1977 indicated the prediction of daily CRW trap catch counts would be difficult. The high SD of ca. 35/.3 on a trap with a mean ca. 400.4 CRW beetles suggests the degree of uncertainty in predicting CRW trap counts on a day-to-day basis.

Research associated with the effects of pheromone concentration, exposed pheromones, trap design, trap height and environmental factors on CRW trap catch variability would further our understanding of pheromone-based monitoring programs.

The potential use for pheromones to assess field populations and predict potential damage needs further study. Pheromone-based research may make it possible to reduce our reliance on general prophylactic insecticide treatments for insect control.

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VIII. APPENDICES

APPENDIX A

Prediction coefficients and R^2 values for WCR trap catch on a 50 ul WCR pheromone extract trap. Environmental variables include temperature, wind speed and relative humidity (Daily hourly readings taken between 0500-0900 and 2000-0100 h).

Variable	Time	Range (During Study)	Prediction Coefficients	R^2
Wind	8 pm	0 - 5.36 (m/sec.)	-19.81*	.100
Humidity	9 pm	42 - 100 (R.H)	11.76*	.140
Humidity	8 am	44 - 100 (R.H)	- 9.94*	.179
Wind	7 am	0 - 7.15 (m/sec.)	-17.71*	.235
Humidity	1 am	50 - 100 (R.H)	- 3.98*	.326
Wind	11 pm	0 - 5.81 (m/sec.)	18.94*	.348
Wind	1 am	0 - 5.81 (m/sec.)	-15.14*	.403
Humidity	9 pm	29 - 100 (R.H)	6.53*	.428
Humidity	10 pm	30 - 100 (R.H)	- 6.70*	.458
Temperature	9 am	12.1 - 29.1 (°C)	23.52*	.487
Temperature	8 am	10.3 - 28.3 (°C)	-22.73*	.589
			CONSTANT: 436.17	

* Significant at the 5% level of significance.

APPENDIX B

Prediction coefficients and R^2 values for WCR trap catch on a 50 ul WCR pheromone extract trap (Daily hourly readings taken between 0500-0900 h).

Variable	Time	Range (During Study)	Prediction Coefficients	R^2
Wind	8 am	0 - 6.26 (m/sec.)	- 3.26*	.065
Wind	5 am	0 - 6.26 (m/sec.)	9.62*	.086
Humidity	5 am	57 - 100 (R.H)	- 4.25*	.110
Humidity	9 am	42 - 100 (R.H)	11.32*	.155
Humidity	8 am	44 - 100 (R.H)	-11.35*	.221
Wind	7 am	0 - 7.15 (m/sec.)	-22.94*	.271
Temperature	8 am	10.3 - 28.3 (°C)	-26.21*	.321
Temperature	9 am	12.1 - 29.1 (°C)	22.27*	.440
			CONSTANT: 811.78	

* Significant at the 5% level of significance.

APPENDIX C

Prediction coefficients and R^2 values for WCR trap catch on a 50 ul WCR pheromone extract trap (Daily hourly readings taken between 2000-0100 h).

Variable	Time	Range (During Study)	Prediction Coefficients	R^2
Wind	8 pm	0 - 5.36 (m/sec.)	-24.24*	.100
Wind	9 pm	0 - 4.46 (m/sec.)	13.08*	.116
Wind	1 am	0 - 5.81 (m/sec.)	-19.00*	.135
Wind	11 pm	0 - 5.81 (m/sec.)	17.90*	.167
Temperature	11 pm	10.7 - 29.4 (°C)	15.18*	.186
Temperature	1 am	10.3 - 28.3 (°C)	-14.57*	.277
		CONSTANT:	109.24	

* Significant at the 5% level of significance.

APPENDIX D

Comparison of CRW beetle per plant counts with their respective daily trap catches (Field A).

Date	1.5 ml Crude Pheromone Baited Trap Catch	Beetle Per Plant Cts.
July 10, 1976	52	1
11	44	1
12	25	1
27	180	6
28	295	6
29	70	6
August 5	546	8
6	200	8
7	75	8
8	1067	8
9	600	8
10	372	8
11	188	8
12	312	8
13	338	8
	$R^2 = .29$	

APPENDIX E

Comparison of CRW beetle per plant counts with their respective daily trap catches (Field B).

Date	1.5 ml Crude Pheromone-Baited Trap Catch	Beetle Per Plant Cts.
July 10, 1976	143	3
11	117	3
12	36	3
27	200	7
28	200	7
29	138	7
August 5	581	9
6	222	9
7	188	9
8	563	9
9	724	9
10	583	9
11	327	8
12	350	8
13	377	8
	$R^2 = .48$	

APPENDIX F

Comparison of CRW beetle per plant counts with their respective daily trap catch from 14 corn fields (Three daily trap catches per field).

Field	Dates	Trap Catch	B/P
1	August 19, 1977	382	.5
	24	290	1.0
	26	578	1.1
2	August 12, 1977	200	.6
	15	376	.8
	17	350	.7
3	August 6, 1977	471	.6
	9	305	.7
	10	333	1.3
4	August 2, 1977	1040	1.0
	4	675	1.2
	8	310	.9
5	August 16, 1977	241	1.8
	19	275	1.0
	22	552	1.6
6	August 23, 1977	1264	1.0
	26	1309	1.05
	30	1496	1.1
7	August 27, 1977	725	1.6
	29	523	2.0
	30	1330	2.8
8	August 25, 1977	1356	1.2
	26	1672	2.1
	30	1723	2.0
9	August 19, 1977	402	2.5
	22	558	2.0
	24	253	1.5
10	August 17, 1977	1150	2.0
	19	473	2.1
	22	850	2.0
11	August 9, 1977	978	3.2
	10,	707	2.8
	12	335	3.1
12	August 26, 1977	1946	3.4
	28	101	2.7
	30	1424	3.1
13	August 23, 1977	97	3.2
	25	1065	3.0
	26	2757	2.9
14	August 23, 1977	113	3.5
	25	672	3.3
	26	2001	3.7

$R^2 = .10$

APPENDIX G

Comparison of CRW beetle per plant counts with their respective daily trap catches from 14 corn fields (First day trap catch).

Field	Dates	Trap Catch	B/P
1	August 19, 1977	382	.5
2	12	200	.6
3	6	471	.6
4	2	1040	1.0
5	16	241	1.8
6	25	1264	1.0
7	27	725	1.6
8	25	1356	1.2
9	19	402	2.5
10	17	1150	2.0
11	9	978	3.2
12	26	1946	3.4
13	23	97	3.2
14	23	113	3.5

$R^2 = .01$

APPENDIX H

Comparison between daily pheromone-baited and non-baited control trap catches (August 17-28, 1977).

Date	50 ul Pheromone-Baited Trap Catch	Non-Baited Control Trap Catch
August 17, 1977	1150	71
18	201	11
19	473	42
20	362	36
21	1080	87
22	850	64
23	244	27
24	235	17
25	755	63
26	945	53
27	491	25
28	65	17

$R^2 = .87$

APPENDIX I

Comparison between daily pheromone-baited and non-baited control trap catches (August 6-25, 1977).

Date	50 ul Pheromone-Baited Trap Catch	Non-Baited Control Trap Catch
August 6, 1977	370	58
7	753	106
8	904	98
9	1212	78
10	972	57
11	517	19
12	350	28
13	688	51
14	269	25
15	723	48
16	183	30
17	643	58
18	68	7
19	276	36
20	130	30
21	543	60
22	433	25
23	61	14
24	181	35
25	615	32

$R^2 = .69$